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APPLIED PHYSICS

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FOR

SECONDARY SCHOOLS

BY

V. D. HAWKINS

HEAD OF THE DEPT. OF SCIENCE
TECHNICAL HIGH SCHOOL
CLEVELAND, OHIO

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PREFACE

Physics ought to be a live subject, a reasonable explanation of the every-day events of life. It seems to the author of this text-book that in recent years the attempt to include in physics a large amount of mathematics and all applications of the principles of the science have resulted in high school texts which are far too difficult for one year for the average high school pupil. *Applied Physics* is a result of an attempt to select the fundamental principles with barely enough common applications to make them clear to the pupil and to bring them home to every-day life, leaving plenty of time for the teacher to supplement with other applications from the pupils' lives which are of local interest and which must differ in every locality.

The author, then, believes that the best methods of teaching the subject are as follows:

1. By a brief text for all of which the pupil will be held responsible, and,

2. By the addition of many interesting local applications to be supplied by both teachers and pupils.

With few exceptions illustrative experiments are not described in the text. They should be performed. A large amount of demonstration work is a great aid to the understanding of the subject. If the illustrative experiments are performed for the class, as they should be, it is useless to cumber the book with a detailed description of them. If they are not performed, a description helps the student very little and causes him to spend too much time in mastering the details of experiments which he does not see and which,

therefore, are difficult for him to understand. The author offers this short text with no apologies but with the conviction that its results will justify it.

The chapter on magnetism and electricity is a departure from tradition. The historical method has been discarded. Every boy has played with a toy magnet, and a start is made from this point of interest. While he has the magnetic field well in mind the dynamo, which is nothing but a loop of wire revolving in a magnetic field, is introduced. The author finds that it is no more difficult for the pupil to understand the three-phase alternator than to master the influence machine. When he has mastered it, he knows how ninety per cent of the electricity used to-day is produced, while the influence machine has a very limited application. In this day of widespread use of electrical appliances every high school student should become familiar with those he meets most commonly.

The author wishes to acknowledge the valuable assistance given by Miss Elizabeth Jackson of the English Department and Mr. Claude Brechner of the Science Department of Technical High School, Cleveland, Ohio. He is also indebted to the C. H. Stoelting Co. of Chicago for permission to reproduce the optical disks on pages 95, 96, and 97.

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APPLIED PHYSICS

INTRODUCTION

Physics has more points of contact with every-day life than any other one science. A bicycle rider runs into a tree and is hurt, an automobile rounds a curve too fast and skids. In either case a policeman may step to a little box, fastened to a pole, and call an ambulance. Man with his little strength lifts great girders weighing many tons, or directs a huge steamship across an ocean, or makes a waterfall furnish him with light, heat, and power. All this is in accordance with the laws of physics. Physics has to do with matter and energy. This is the study of the laws of nature which control everything happening about us. Ignorance of the law excuses no one. Nature's laws will hold anyway and the wise man will learn to use them to his advantage.

Matter. No one knows what matter is. There is a theory that it may be made up of molecules and these in turn formed from smaller particles called atoms, which are in turn composed of smaller particles. In accordance with this theory, the symbol for water is written H_2O, which means that a molecule of water is made of two atoms of hydrogen and one atom of oxygen.

Energy is the ability to work. We shall meet energy in many forms, chemical energy, electrical, mechanical, heat, light, etc. The quantity of matter and of energy in the universe is constant. *We know that when energy disappears in one form it appears in another form with*

no change in amount and that if matter disappears in one form it appears in another and that the amount is the same. This is the law of conservation of energy and of matter.

The relations of energy and matter are so exact that physics must be an exact mathematical science. The student must have a definite set of units to compare quantities, and these units must be real and definite. That is, "inch" must be not simply a word, it must be a definite length which is suggested by the word. For that reason instead of trying to define the units here, we shall give an introduction to them in the first experiments in the laboratory. We use a convenient decimal system of money and laugh at the clumsy English system of pounds, shillings, pence, etc., and yet we cling to the English system of miles, rods, feet, etc., while the continent of Europe has long been using a decimal system. The student of science in this country will need to be familiar with both. The units of both systems are arbitrary, that is, when first chosen they could as well have been different but they have now been commonly accepted and each government has made accurate duplicates of the units and holds them as standards. In the C.G.S. (centimeter-gram-second) system, the centimeter is the unit of length, the gram the unit of mass, and the second the unit of time. Other units are built up from these.

A short time spent in the laboratory with meter stick and yard stick, English and metric weights, will be of more value to the pupil than many pages of explanation.

CHAPTER I

MACHINES

We see a hod of brick carried up to the second story or a heavy barrel rolled up a skid on to a dray, and call it work. We may not all have in mind the same definition of work and the same unit for measuring it. If you hold a five-pound weight out at arm's length all day, holding it in the same place all the time, do you do any work? Place a post under the same weight holding it in the same place and leave it there all day. The post will have to do the same work that you did. Is the foundation of your school building doing any work when it supports the weight of the walls? What is work, then? If a weight be lifted from the bottom of a clock to the top it can be made to turn the wheels as it runs down. Water stored at the top of a hill will turn the mill wheels as it runs down. We all know from experience that in order to move any object we must give it either a push or a pull, which we call force. Force is a push or a pull which tends to produce motion. Work is force acting against a resistance and *moving* it.

When we wish to compare distances, we have the units of length — foot, meter, etc. Without them the architect could not make specifications for the contractor. To compare forces, we have the pound unit, which is the pull of gravity upon a standard weight kept by the government. The unit of work, the foot-pound, is a force of one pound pushing or pulling through a distance of one foot. A ten-pound weight lifted through two feet would require 2×10,

or 20 foot-pounds of work. Work requires two factors, force and the distance through which it moves. If a man were hired to carry two tons of coal upstairs and spent the day leaning against the bin, that is, pushing against it, he would accomplish no work. Is it possible to exert force without doing work? How much work is done when a 130-pound boy climbs from the first to the second floor, 15 feet? How much work is done when the same boy pushes against the side of the house for half an hour? If a pull of 300 pounds pulls a car along a track for 10 feet, 10×300, or 3000 foot-pounds of work is done overcoming friction.

Often a pry or lever is used for lifting heavy weights. In Fig. 1, if a force be applied vertically at F and move the distance (a), while the lever moves about the pivot (p), the weight is lifted the distance (b).

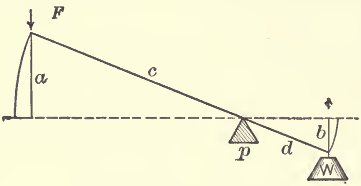


Fig. 1. — Lever.

By a lever a man may lift many times his own weight. He makes use of the principles of physics.

Every boy knows that he can lift many times his own weight by using such a lever. He also knows that the distance (b) which the weight is lifted is small compared to (a) when the weight is heavy. There is little loss due to friction in the lever. Repeated experiment has shown that if $W = 500$ pounds and is lifted 1 foot while F drops 5 feet, F must be 100 pounds. The force F is doing work on the lever, 100×5, or, 500 foot-pounds. The work given back is $500 \times 1 = 500$ foot-pounds. The work given out by a machine can never be more than the work done on the machine. In practice a part of the work done on the machine is used by friction and is useless work, so that the useful work from the machine is only a fraction of the total work done on the machine. This fraction

is called the per cent efficiency. A machine which, for every 100 foot-pounds of work received, gives back 75 has 75% efficiency. If we could build machines having no friction they would have 100% efficiency. The so-called perpetual motion machine is impossible.

Neglecting friction, the work done by a machine is equal to the work done on the machine. Expressed as an equation, $\mathbf{F} \times \mathbf{D} = \mathbf{W} \times \mathbf{d}$, where F = force in pounds, D = feet the force moves, W = resistance in pounds, d = feet the resistance moves. That is, neglecting friction, **the force times the distance that it moves equals the resistance times the distance that it moves.** This one fundamental principle of machines well mixed with common sense will work all the problems in simple machines, which the student is likely to meet.

In Fig. 1 for instance, this gives us $F \times a = W \times b$ or $\frac{W}{F} = \frac{a}{b}$ but by similar triangles $\frac{a}{b} = \frac{c}{d}$; therefore $F \times c = W \times d$. Force times the force arm = weight times the weight arm. The ratio $\frac{\text{Weight}}{\text{Force}}$ or $\frac{\text{distance the force moves}}{\text{distance the weight is lifted}}$ is called the mechanical advantage of a machine.

Any contrivance for transforming or transferring energy *is a machine.* There are *six simple machines.* In considering machines, never forget the principle already stated that the *total amount of energy in the universe is constant.* It is not possible to get more work out of a machine than is done upon it.

In the operation of a machine, *there are always two quantities* of work to be considered, the work done upon the machine and the work done by it. The work done by the machine equals the work done upon it. Some of the work done by the machine may be used up in overcoming friction. In this case the *effective work done by* the machine

is less than the work done upon it. The ratio of the useful work to the total work, expressed in per cent, is the efficiency of the machine. The efficiency of a simple lever may be almost 100%. The efficiency of a motor may amount to 85%. The efficiency of a locomotive may be about 10%.

The machine elements are lever, wheel and axle, pulley, inclined plane, screw, and wedge. Other machines are formed by combining these.

A lever is a bar capable of being turned about a pivot, as in Figs. 2, 3, and 4 where F is the force, (p) the pivot or fulcrum, W the weight, (a) the force arm and (b) the weight arm.

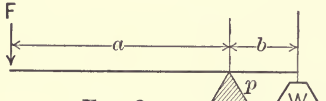


FIG. 2.

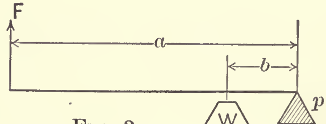


FIG. 3.

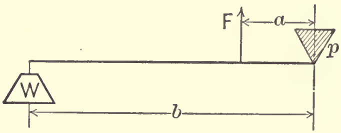


FIG. 4.

Three classes of levers, *one* law $W \times b = F \times a$.

The force times the force arm equals the weight times the weight arm; the mechanical advantage of the lever also equals the inverse ratio of its arms.

In the lever the force tends to turn the lever one way while the weight tends to revolve it the other way. This tendency to cause rotation is called a moment.

The product of the force and the force arm is its moment and the product of the weight and the weight arm is its moment. In the lever the two moments are equal and opposite.

The wheel and axle, Fig. 5, is a modified lever. It consists of a wheel and axle rigidly fastened together to turn about a common axis. It is evident that the radius of the axle (r), is the weight arm, and the radius of the wheel, R, is the force arm. The wheel may be replaced by a crank, as in the windlass.

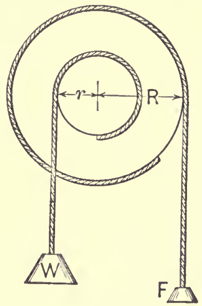


Fig. 5.
Wheel and axle, a lever with another name.

In a train of gear wheels the resistance of one becomes the force of the next, and by continued application of the laws of the lever the following law may be obtained: *The weight times the continued product of the radii of the axles equals the force times the continued product of the radii of the wheels.*

Pulleys. Pulleys for the transmission of power by means of belts are readily considered by means of the principles of the wheel and axle. *Power* is the time rate of doing work. To lift a ton of coal from the basement to the first floor requires the same number of foot-pounds of work (weight times distance lifted) whether it takes a week or a minute. The power required is very different; 33,000 *foot-pounds* of work per minute or 550 foot-pounds per second is *one horse-power.*

To lift 231,000 pounds 5 feet in 7 minutes would require $5 \times 231{,}000$ or 1,155,000 foot-pounds of work in 7 minutes or 165,000 foot-pounds in one minute; $165{,}000 \div 33{,}000 =$ 5 horse-power.

The pulley which imparts motion to the belt is called the *driver;* that which receives the motion is called the *driven.* If a 12-inch and a 6-inch pulley are belted together, the 6-inch pulley will make two revolutions while the 12-inch is making one. The number of revolutions is inversely proportional to the diameters. Rubber, cotton, and leather

belts are used. The force tending to turn the pulley (effective pull) is the difference between the tension on the slack side and that on the driving side. To determine what width of the belt to use, it is necessary to know the arc of contact on the small pulley, the velocity of the belt, the power to be transmitted, and a constant depending upon the friction and the arc of contact.

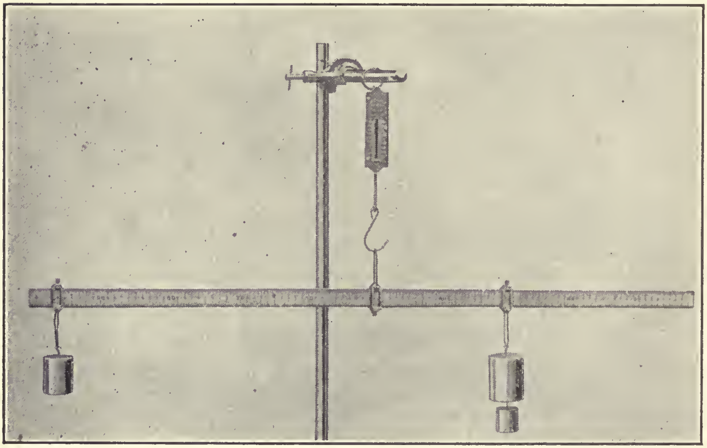


FIG. 6. — A Lever.

The law of levers is easily tested and demonstrated by simple apparatus. Weight × weight arm = Force × force arm.

Parallel forces are also illustrated. The sum of the weights and the weight of the meter stick equals the scale reading. A team of horses pulling on an evener and many other applications should be suggested and explained by this picture.

In getting the length of a belt for pulleys not yet in place, the millwright uses the approximate rule $3\frac{1}{4}$ times half the sum of the diameters of the two pulleys plus twice the distance between the centers of the pulleys. This will furnish an estimate for an open belt. After the pulleys

are in place a tape is used to measure the length required for the actual cut.

To get the width of a s'ngle belt let

k = the allowable effective pull per inch given above.
H = the horse-power to be transmitted.
v = the velocity of belt in feet per minute.
w = width in inches.

$$w = \frac{33{,}000\ H}{vk}$$

Do not learn this formula but study it until the reason for each part is understood, and then analyze each problem, working without the formula.

33,000 H gives the number of foot-pounds of work per minute. Work is the product of force times distance and the velocity in feet per minute of the belt multiplied by the allowable effective pull per inch of width gives the number of foot-pounds one inch width will do per minute. This divided into the number to be done per minute gives the width of the belt required.

What width of belt will be required to transmit 10 horse-power, the speed of the belt being 1,500 feet per minute and the arc of contact being 135 degrees on the small pulley, if the allowable pull per inch width is 31.3 pounds?

$$w = \frac{10 \times 33{,}000}{1{,}500 \times 31.3} = 7 \text{ inches nearly.}$$

It is evident that if the speed is increased greater power may be transmitted at the same tension.

Problems

1. A belt running 1000 feet per minute has an effective pull of 33 pounds. What horse-power is it transmitting?
2. What effective pull must a belt have to transmit 5 horse-power when running 800 feet per minute? when running 1600 feet per minute?

3. The driver running 500 R.P.M. (revolutions per minute) is 12 inches in diameter, the belt is six inches wide with an effective pull of 30 pounds per inch. What horse-power is it transmitting? The pupil should always look for the easiest method of working applied problems. Note here that the surface speed must be in feet per minute. Use the diameter as 1 foot. Use $\frac{22}{7}$ for *Pi*. Indicate the work before multiplying any of it, as follows:

$$\frac{1 \times 22 \times 500 \times 6 \times 30}{7 \times 33000} = H.P.$$

4. A driving pulley 20 inches in diameter makes 180 R.P.M. What is the diameter of the follower making 450 R.P.M.?

5. A main line shaft running 200 R.P.M. has a 32-inch driver belted to an 8-inch follower on the first counter; a 20-inch driver on the first counter to a 6-inch driver on the second counter; and a 12-inch driver on the second counter to a $2\frac{1}{2}$-inch pulley on a spindle. Find the R.P.M. of the spindle.

6. What width of belt will be required to transmit 12 H.P., the speed of the belt being 1200 feet per minute and the allowable effective pull 40 pounds per inch width?

7. If both driver and follower in problem 6 are 18 inches in diameter find R.P.M. What is the effective pull? If 12-inch pulleys are substituted on both driver and follower, and the R.P.M. and H.P. remain the same, how are width of belt, effective pull, and speed of belt affected?

Work is always the product of two factors, force times distance, and power is rate of doing work. Whenever a problem involves quantity of work, look for the two factors.

8. In Fig. 5 r is 4 inches and R is 12 inches and there is no friction, What force will be required to balance 600 lb. at W? If $\frac{1}{5}$ of the work done on the machine is lost in friction, how much weight will this same force lift? In the second case what is the efficiency?

In Fig. 7 suppose the shafts a and b are parallel, the pulley at a being cone-shaped as shown. The circumference on the right-hand side being larger than that on the left the belt is drawn ahead more rapidly than the other side of the belt and the belt is thrown to the right and shows a tendency to climb to the large side of the cone. Suppose

the pulley is made of two cones with the large diameters placed together. The belt will be held in place as each side will tend to climb toward the center. This is done by crowning the pulley as in *c*.

Problems

1. In pulling a railroad spike a crowbar is used in which the long arm is 4 feet and the claw is 3 inches long. If it requires a force of 50 pounds to pull the spike, what is the resistance of the spike?

2. In the forge room the machine for cutting bar iron has a lever 6 feet long, with the knife connected 4 inches from the pivot end; the knife is 2 feet long with a bar of iron placed under it 2 inches from the pivot end. When a boy pulls 100 pounds on the end of the lever, what is the pressure on the bar of iron? What is the strain on each pivot?

3. A belt with a speed of 1000 feet per minute has an effective pull of 33 pounds. How much work is it doing per minute? What horse-power is it transmitting?

4. Twelve boys weighing 110 lb. each are lifted from the basement to the third floor, 40 feet. How much work is done, neglecting friction? What horse-power would be required if this takes one minute? Two minutes?

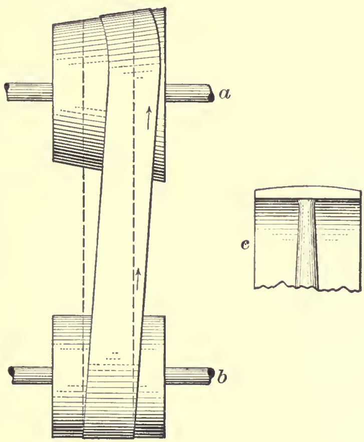


FIG. 7.

A belt will run better on a crowned pulley than on a flat one.

5. If 5000 pounds of water per day are pumped from the basement to the fountain on the third floor, 45 feet, how much useful work is done? If the friction of the pump uses one fifth the energy supplied, how much work must be done on the pump? If the motor running the pump has 60% efficiency, how many foot-pounds of electrical energy will be required by the motor? What horse-power motor must be used?

Pulleys are also used for raising or hoisting loads in which case the frame supporting the axle of the pulley is a block.

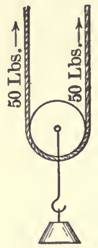


FIG. 8.

Each rope must support part of the load.

A fixed pulley is one whose block is not movable. A movable pulley is one whose block is movable.

If a boy weighing 100 pounds be in a swing each rope supports 50 pounds. If a weight of 20 pounds be supported by one movable pulley as in Fig. 8, each rope is under a tension of 10 pounds. By extending this principle we may state the law that in any combination of pulleys where one continuous rope is used the mechanical advantage is equal to the number of times the rope passes from one block to another. In actual practice it is found that the efficiency runs from 60% to 90%, depending upon the condition and number of the sheaves.

A combination of pulleys frequently used has three *sheaves* (wheels) in each block. There are six ropes running between the blocks. If we neglect friction, when a force of 100 pounds is exerted on the free end of the rope, each rope is put under a strain of 100 pounds and a weight of 600 pounds will be supported. In order to remove one foot of rope from each of the six supporting the weight the force must move through six feet. See Fig. 9.

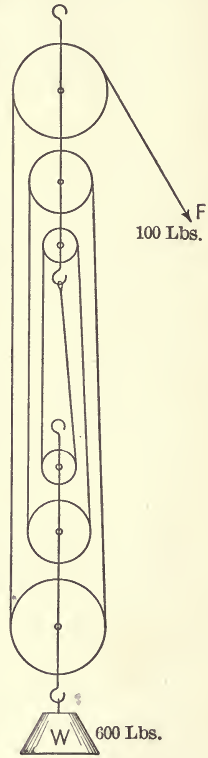


FIG. 9.

Block and tackle, for lifting heavy objects.

Man applies the laws of physics, and machines save much of his heavy drudgery and do many things beyond the strength of the strongest animal.

An inclined plane is one making an angle with the horizontal as in Fig. 10. Where the force acts parallel to the plane, as in Fig. 10, the effort must move through a distance equal to the length while the load is lifted through the height (h). The mechanical advantage is l/h. If a plank 16 feet long be used in lifting a weight of 600 pounds up to a platform 4 feet high, and the force be applied parallel to the plank, what effort will be required to move it? $16 \div 4 = 4$, the mechanical advantage. $600 \div 4 = 150$ pounds required, neglecting friction.

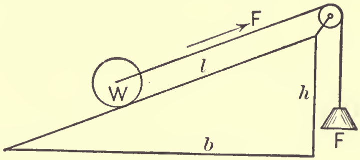


Fig. 10.

When the force is applied parallel to the base the mechanical advantage is the base (b), divided by the height (h).

A special application of the inclined plane is the wedge. It may be used for moving heavy weights or in the form of key used in fastening crank to crank shaft.

If a right triangle be wound around a cylinder with one leg forming the circumference, the hypotenuse takes the form of a helix. A helical projection winding around the circumference of a cylinder forms a screw. The projection is the thread, the distance between the threads is the lead, the number of threads to the inch is the pitch. In the case of the jack screw for lifting heavy weights, the effort is applied to the end of the lever. When the screw makes a complete revolution the weight is lifted through a distance equal to the lead, while the effort moves through the circumference of a circle with a lever as a radius. It is found in practice that the friction is so great that the screw will lift only about one-fifth of the theoretical weight, that is, its efficiency is only about 20%. With a screw having four threads to the inch a man exerts a force of 40 pounds at

the end of a four-foot lever. What theoretical load can he lift? If the efficiency is 20%, what load can he actually lift?

Problems

1. Two beams are fastened together with a bolt which has an 8-pitch thread. A monkey-wrench one foot long is used to tighten the nut. If a force of 50 pounds be exerted and one half be lost in friction, how tight are the timbers squeezed? (Use Pi as $3\frac{1}{7}$ and get only approximate result mentally.)

2. A skid 16 feet long is used in pushing an 800-pound barrel on to a dray 4 feet high. What push must be exerted against the barrel? How much work is done? (Find the work in two ways.)

3. In pushing an 800-pound barrel on to a platform, the skid forms an angle of 30° with the horizontal plane. What force is required?

4. A weight of 141 pounds rests on a plane which is at 45° to the horizontal. What force is required to hold it in place?

The micrometer, Fig. 11, much used in machine shops, is an application of the principle of the screw. The screw (*a*) is 40 pitch. The thimble (*b*) is fast to the screw. The beveled edge of *b* is divided into 25 equal parts. Fastened firmly to the frame is a sleeve (*c*) upon which is a scale corresponding to the lead of the screw, that is, each division is $\frac{1}{40}$ or .025 of an inch.

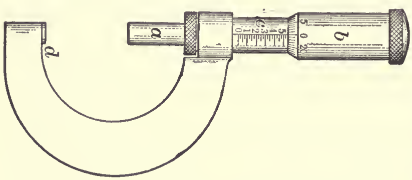


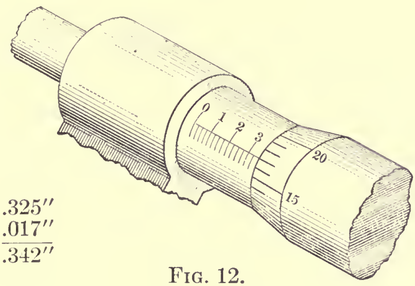
FIG. 11. — Micrometer Caliper.

Accurate measurements and fine adjustments in modern shop practice are made by means of the micrometer screw.

When screw (*a*) is against anvil (*d*) the zero lines coincide. Then each complete turn of the screw (*a*) represents a longitudinal movement of .025 inch. One division on *b* means $\frac{1}{25}$ of a turn and therefore a separation of the jaws $\frac{1}{25}$ of $\frac{1}{40}$ or .001 inch. Fig. 12 shows a sleeve reading of .325 inch and thimble reading of .017 or a total of .342 inch.

Problems

1. State the general rule of machines, expressing the relation between force and weight and the distances through which they move.



.325″
.017″
.342″

Fig. 12.

2. If the force arm of a lever is 20 inches and the weight arm is $2\frac{1}{2}$ inches, what force will be required to lift a weight of 100 pounds?

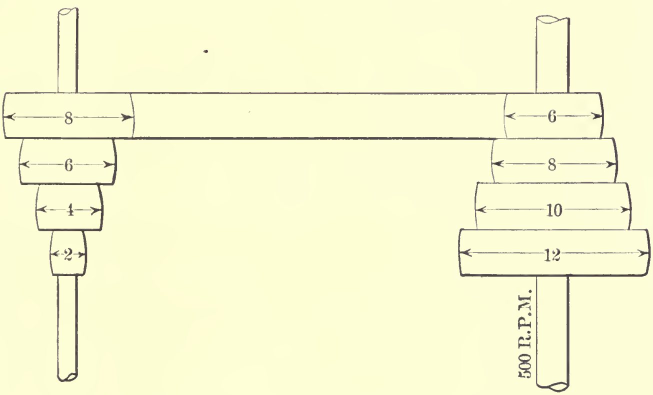


Fig. 13. — Pulley Cone, Problem 9.

By running the belt on different combinations, several speeds may be obtained for the machine.

3. What must be the speed of the driver, 12 inches in diameter, in order that the driven, with a diameter of 5 inches, may make 1000 R.P.M.?

4. A single belt running at 1650 feet per minute is used to transmit 40 horse-power. If the allowable pull per inch width is 35 lb., what width of belt will be required?

5. In a set of pulleys there are three wheels in the movable block and six ropes passing from one block to another neglecting friction, what force will be necessary to lift 1200 pounds? If the efficiency of this combination is only 80%, what load will the same force lift? What is the mechanical advantage of this combination?

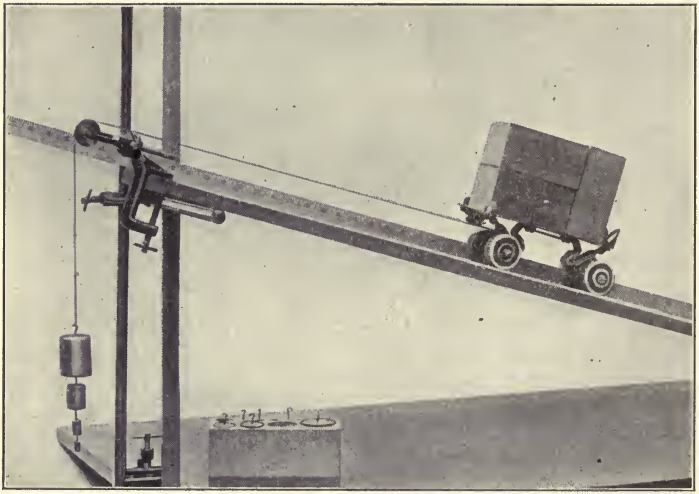


FIG. 14. — The Principles of Simple Machines.
Simple apparatus for demonstrating the principles of simple machines.

6. If a railroad track has a rise of 6 inches in 200 feet of its length, what force pulling on the draw bar will be necessary to hold a car without friction, weighing 10 tons and loaded with 40 tons? If the same car is being pulled up this incline 20 feet per second, what horse-power is used? If 200 pounds pull is necessary to overcome the friction of the car, what horse-power is used in overcoming friction at the above rate?

7. Measure the chain of gears on a planer in the machine shop and compute the mechanical advantage.

8. There are several screw presses in the building. Neglecting friction, find the pressure exerted by ten pounds pull on the wheel of one of them.

9. If in the turning shop the shaft has a speed of 500 R.P.M. and a pulley cone is used having diameters 6, 8, 10, and 12 inches while a lathe has a pulley cone with diameters of 8, 6, 4, and 2 inches, what speed will the lathe have on each combination? See Fig. 13.

10. In the first combination of the above problem, what effective pull must the belt have to transmit 3 horsepower?

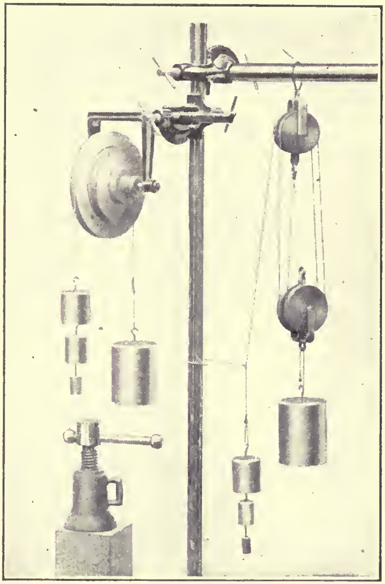


Fig. 15. — The Principles of Simple Machines.

Simple apparatus for demonstrating the principles of simple machines.

The Prony brake is commonly used to measure the delivered or brake horse-power of an engine or the brake horse-power at the shafting in any part of a shop. As shown in the Fig. 16, two pieces of timber are fitted to a pulley and placed as shown. A long lever arm L is bolted to the pieces, and with the pulley standing still a weight (x) is placed to balance the arm L. The pulley is revolved left-handedly at speed and a weight (w) gradually added until the friction on p is all it will carry and stay up to speed. Horse-power is speed in feet per minute multiplied by force divided by 33,000. Surface speed $= 2\pi Nr$, and force $= WR/r$. Therefore, the foot-pounds per minute $= \dfrac{2\pi RNrW}{r}$ and

the r divides out, hence the horse-power $= \dfrac{2\pi RNW}{33{,}000}$

N = Revolutions per minute.
W = weight.
R = arm in feet.

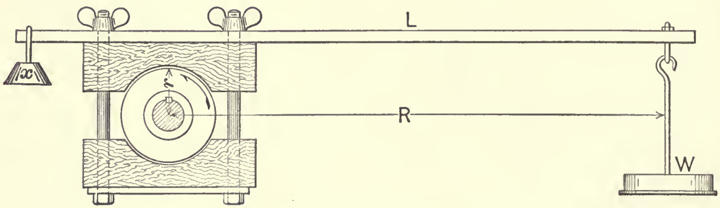


FIG. 16. — The Prony Brake.

A brake with an arm 5 feet long was placed on a gas engine. The pulley made 300 revolutions per minute and the brake balanced with a twelve-pound weight. What horse-power was developed?

$$HP = \frac{2 \times 3.1416 \times 5 \times 300 \times 12}{33{,}000} \text{ or } 3.4$$

Problems

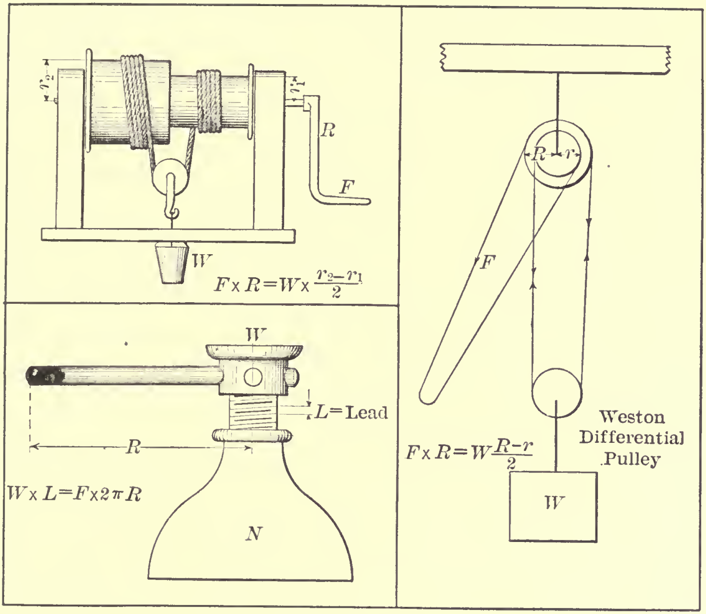
1. Work is the product of two factors, force and distance. Where do these two appear in the formula for the Prony brake?

2. Where do the two factors of work appear when power is being transmitted from a shaft to a machine by means of pulleys and belt?

3. Why has every perpetual motion machine so far invented failed to work?

4. How might a micrometer be constructed to read to 1/500 of an inch?

5. If a train is pulled at a uniform speed along a level track, is any work done against gravity? Is any work done? If so what becomes of the energy thus used?



FIGS. 17, 18, 19.

Start with general principle of machines. (*Neglecting friction, the force times the distance it moves equals the resistance times the distance it moves*) prove the formulæ, opposite Figs. 17, 18, and 19.

Problems

1. In testing a small motor with the Prony brake, the brake arm is 30 inches long, weight 3 pounds, motor running 900 R.P.M. Find brake horse-power.

2. An engine making 200 R.P.M. will support 500 pounds at the end of a six-foot lever. What is the horse-power?

3. A gasoline engine making 1100 R.P.M. balances a 25-pound weight at the end of a 4-foot lever. What is the horse-power?

4. If in Fig. 5, R is a crank 15 inches long (r) is 2 inches and the rope (w) is fastened to F of Fig. 9, what load (w) will a force of 100 pounds lift if the combined machine works at 60% efficiency? How far will the crank move to lift the weight 5 feet?

6. If the front sprocket of a bicycle contains 27 teeth and the rear one 9, how far will the wheel move along the ground while the pedal makes one turn? How many turns of the pedal per mile?

7. If the crank (problem 6) is 7 inches long how far does the wheel move along the ground while the pedal moves one foot?

8. When the crank is in the horizontal position what is the mechanical advantage? If the efficiency is 80% how much is the forward push when a force of 50 pounds is exerted on the pedal?

9. What is the "gear" of the above bicycle? Why will a low gear climb hills better than a high gear? Why will a high gear run faster than a low gear on a smooth level pavement?

10. Suppose R be $4\frac{1}{4}$ inches and r be 4 inches and a force of 100 pounds be exerted at F, Fig. 19, what load can be lifted? Consider the efficiency to be 75%.

11. Refer to Fig. 13, page 15. With the driver running at 500 R.P.M. compare the speed of the driven and the mechanical advantage of each combination.

12. A shaft and a counter-shaft each have a pulley one foot in diameter. The shaft runs 1000 R.P.M. and 4 horse-power is being transmitted, find speed of belt, effective pull, and R.P.M. of counter-shaft if there is no slip. Find the same if pulleys 2 feet in diameter are substituted on both line shaft and counter-shaft.

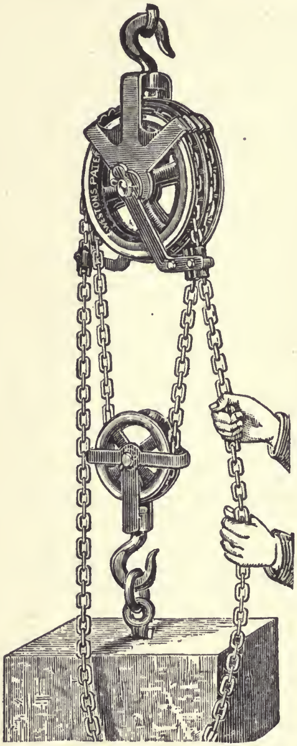


Fig. 20. — Weston Differential Pulley.

The wheels of the pulley are fastened rigidly together. One wheel is a little larger than the other and revolving the wheels once lifts the weight half the difference between the circumferences.

CHAPTER II

DYNAMICS

Dynamics treats of force producing motion. Watch a locomotive starting a heavy freight train. How slowly the train starts. It gradually moves faster and faster until it is at full speed. When the breaks are set the friction with the rails pulls back on the train and soon stops it. If a train runs at high speed around a curve it presses against the outer rail. We might say the outer rail pushes against the train pushing it out of a straight line. If you tie a string to a lead ball and swing it in a circle you must pull on the string to keep the ball in the curved path. Such a push or pull is called force. *That which changes or tends to change motion in direction or quantity is force.*

If you push against the side of a building, the building will not move, yet if you exert the same push on a light wagon it will move. In each case you used force, but in one case motion is produced and not in the other, because the resistance is too great. We found that work expressed in foot-pounds required two factors, force times distance. We must agree, then, that force may be exerted without doing any work, as when you push against the side of a house.

Motion is change of position with reference to some other body. On a fast train one day a mother said to her little girl, " Now, Susan, do sit still." The train was running 60 miles an hour which is 88 feet per second. What do you think about sitting still? The rate of motion, the speed,

the number of units of space passed over in one unit of time, is velocity. Velocity may be either constant or variable. When the velocity is variable the change in speed per unit time is called acceleration and may be either an increase or decrease in speed.

Forces can be compared only by their tendency to produce or change motion. Sir Isaac Newton stated the relation between force and motion in three laws:

1. All bodies continue in a state of rest, or of uniform motion in a straight line, unless acted upon by some external force that compels a change.

2. Every change of motion is proportional to the acting force, and takes place in the direction in which the force acts.

3. To every force there is always an equal reaction in the opposite direction.

The first law, often called the law of inertia, states that a body once put in motion by any force will keep on forever in a straight line unless some force acts upon it. Inertia is not a force, and should not be considered as such. A car moving with a high velocity may strike a blow upon a stationary body and expend considerable energy in doing damage. The force which it exerts is not force of inertia but is due to inertia. The amount of work it is able to do while coming to rest is the same as the amount of work done upon it in starting it from rest to the given velocity. Inertia has enabled it to store the energy in itself.

The second law has many important applications. If a ball be thrown due north and the wind is blowing from the east, the ball will be blown out of a straight line and toward the west. The distance it is moved toward the west will depend upon the velocity of the wind and will be the same per second regardless of its velocity toward the north.

Two marbles, shot out from a table top, one to fall straight down and the other shot out in a horizontal direction, will strike the floor at the same time. See Fig. 21.

We see that gravity acted on each ball in exactly the same way, and produced the same downward motion regardless of other motion. This is all as it should be, as stated in the second law of motion. A more complete explanation of the term "change of motion" will be found on page 27.

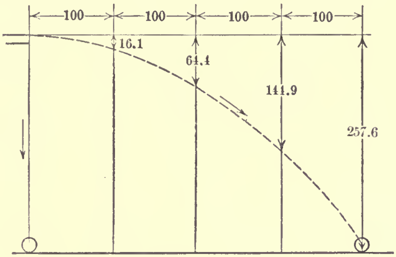


Fig. 21.

A boy weighing 120 pounds can usually lift more than his own weight. Now, suppose he stands in the rings in the gymnasium and taking a rope in each hand lifts 150 pounds. He weighs only 120 pounds. Will he lift himself any farther than the ceiling of the gymnasium? Explain this by the third law of motion.

When two or more forces act upon a body at the same time at a common point, their combined effect, called the resultant, may be found by the parallelogram of the forces.

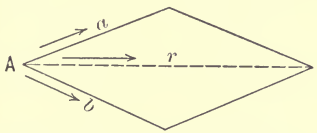


Fig. 22. — Parallelogram of Forces.

a and *b* combine to produce the resultant *r*.

A force may be represented by a straight line, the direction being the direction of the force and the length being the force drawn to scale. If two forces (*a*) and (*b*) act on a body at *A* as in Fig. 22, draw the line in the direction of the forces and lay them off to some convenient scale. Complete the parallelogram as in 22, and the diagonal represents the resultant force both in direction and size. A third

force acting at A, equal and opposite to r, will balance the forces a and b and prevent motion.

For an application of the parallelogram of forces refer

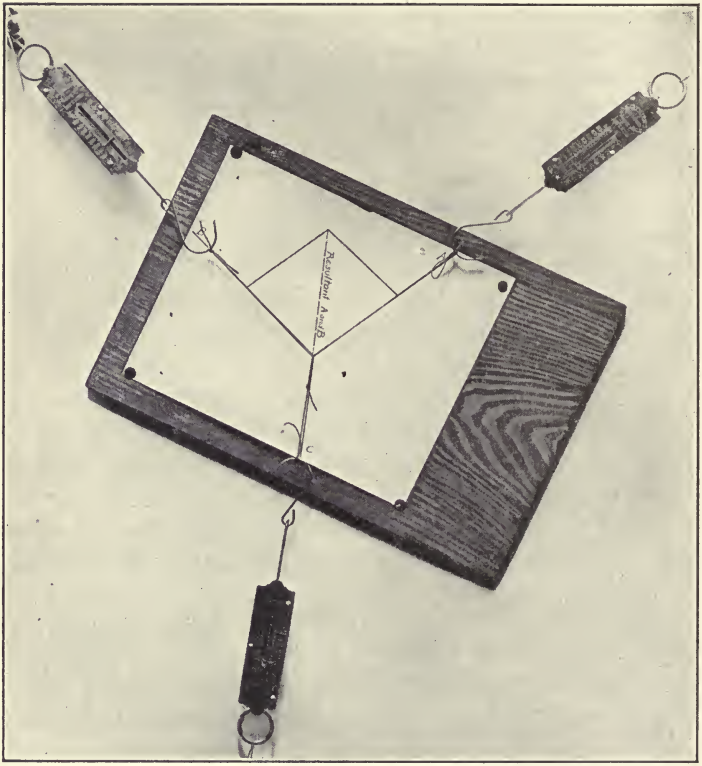


FIG. 23. — Proving the Parallelogram of Forces.

The resultant of A and B is equal to and opposite C. A tug of war with the opposing teams evenly matched.

to Fig. 24. The end pole of a telephone line of 6 wires must be held in by a guy wire. Each line is under tension

of about 200 pounds. The guy is fastened at 45°, how much will it have to pull? The guy is made by twisting together wires. If each wire will hold 500 pounds before breaking, and two extra are to be put in for safety, how many wires must be used in the guy?

The parallelogram of forces may be used in explaining

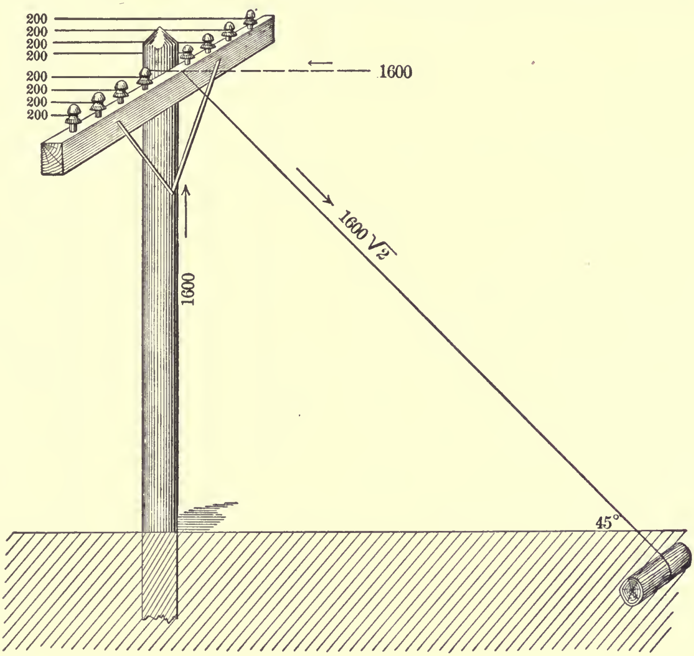


FIG. 24.

The "Line Boss" often estimates the number of wires needed in a guy by drawing a parallelogram in the dust of the road.

the flight of a kite or of the heavier-than-air flying machine, the aeroplane. The kite is pulled forward by a string or the aeroplane is forced forward in the direction d, Fig. 25, by the action of the propeller. This motion causes the air resistance

to develop a pressure against the plane in the direction *c* perpendicular to the plane. This may be resolved into two forces, one, *a*, resisting the motion of the plane, and one, *b*, opposed to the weight of the machine. If the speed be great and the planes are large the portion *b* will be equal to or greater than the weight and the plane will rise. Means of stability and steering must be provided by auxiliary planes and rudders.

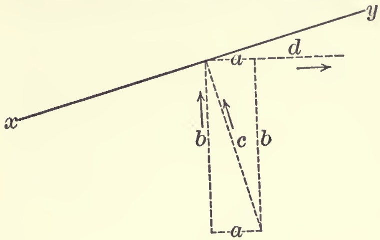


Fig. 25.

Problems

1. Neglecting weight of *b*, Fig. 27, what is the tension on *c*? Compare with Fig. 22.

2. If in the Fig. 27 the weight of *b* be 50 pounds, how much does it add to the tension of *c*?

3. If in Fig. 24 the guy wire makes an angle of 60° with the horizontal, how many strands must be placed in the guy?

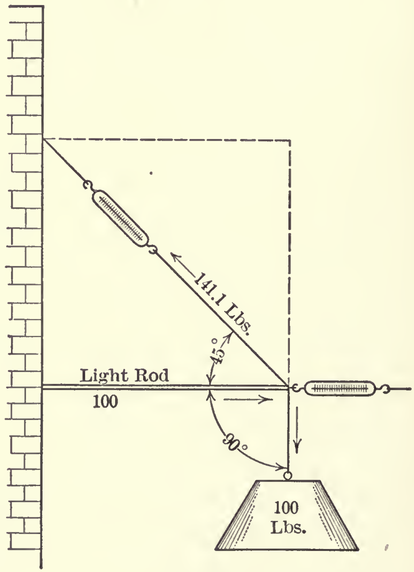
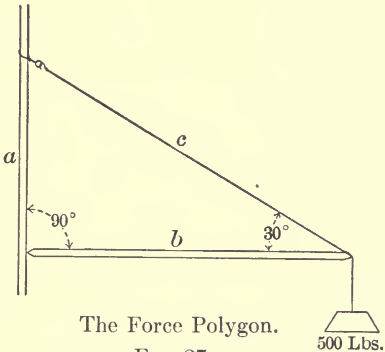


Fig. 26.

When a locomotive starts a heavy train from rest, it does not reach full speed at once but increases its rate of motion slowly. If you kick a football and some boy has made a mistake on the first of April and filled the ball with lead instead of air, you will

find that a heavy body does not start from rest easily. This helplessness of matter is *Inertia*. Inertia causes a body in motion to keep on in a straight line unless acted on by some force; it keeps a body at rest from starting unless some force starts it. Inertia is a property of all matter and is proportional to the amount of matter present. In the case of the train starting, it takes time and force to overcome the inertia of the train, and when the train is running 60 miles per hour it takes time and force to stop it.



The Force Polygon.
FIG. 27.

Suppose a locomotive be coupled to a heavy train which is carried on such perfect bearings that it has no friction. If the engine pulls for one second it will start the train a little. If the coupling breaks at the end of the second, the train will run during the next second with a constant speed. Suppose the train starts from rest and at the end of one second has a speed of one foot per second, that is, if left to itself, would run one foot the next second. At the end of two seconds it has a speed of two feet per second, at the end of three seconds it has a velocity of three feet per second, and so on until it is running at full speed. The increase in speed per unit time is acceleration, and in this case is the same each second and is therefore uniform acceleration. The speed increases one foot per second every second. That is, if we have a body free to move without friction and couple a force which exerts the same pull all the time in one direction, the body will begin to move slowly at first and at the end of one

second will have a certain speed. At the end of two seconds it will have twice as great a speed and at the end of three seconds three times as much speed and so on. Such a force is a constant force, and such increase of speed is constant or uniform acceleration, and the motion is uniformly accelerated motion. The velocity equals the acceleration times the time if the body starts from rest. $V = at$ is the same thing in a formula which must be learned.

A train starting from Chicago runs for a while at 50 miles per hour; after stopping at a small station it runs at a slower speed for a time. At the end of five hours it is found that including all stops and changes of speed it has averaged 30 miles per hour. How far has it traveled? You answer at once 150 miles or the average speed times the time equals the distance traveled. If a body starts from rest and moves with a uniform acceleration so that its increase in speed is 4 feet per second each second, at the end of three seconds it will have a velocity of 4×3 or 12 feet per second. Experiments have shown that its average speed is the average of the speed at the beginning and at the end of the time when it has uniform acceleration. In this case the average of 0 and 12 is $(0 + 12) \div 2 = 6$. The distance traveled is $6 \times 3 = 18$ feet. Suppose the body has an acceleration of a feet per second each second, then at the end of t seconds its speed will be $v = at$ feet per second. Its average speed is $(at + 0) \div 2$ or $\frac{1}{2}at$. The distance traveled is the time (t) multiplied by the average velocity, ($\frac{1}{2}at$), that is $(\frac{1}{2}at) \times t = \frac{1}{2}at^2$. The formula is written $S = \frac{1}{2}at^2$. S is the distance traveled, a the acceleration per second, and t the time in seconds.

Sometimes we wish to find the distance traveled in any one second, as the fifth second. Suppose a body starting from rest receives a uniform acceleration of 6 feet per second each second, how far will it travel in the fifth second? Its

velocity at the end of 5 seconds is $5 \times 6 = 30$ feet per second. At the beginning of the fifth second it is $4 \times 6 = 24$ feet per second. The average velocity is $\frac{1}{2}(30 + 24)$ or 27. The distance traveled for the fifth second is the average velocity,

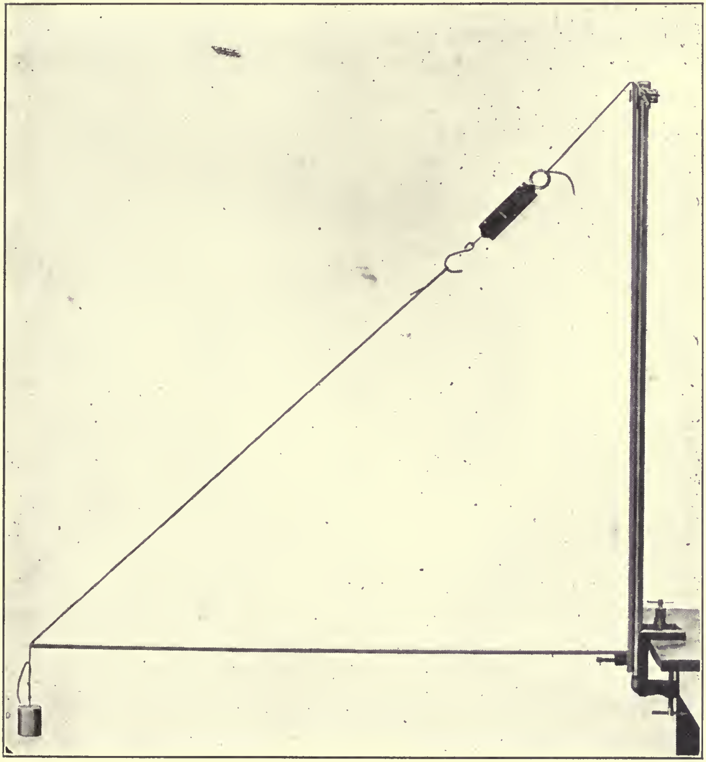


Fig. 28. — Stick, String, and Spring Balance.

Only a stick, string, and spring balance required to illustrate several important applications of physics in trusses, hoisting cranes, etc. Every student of physics should experiment with several combinations, and apply his results to many local illustrations. See Figs. 22 and 23.

27, multiplied by the time, or $27 \times 1 = 27$ feet. For the general formula find out how far a body receiving uniform acceleration travels the second (t) which may be the fifth or any other second. At the end of the second (t) the velocity is at. At the beginning of the second it is $(at - a)$. The average speed is $(at + at - a) \div 2$ or $\frac{1}{2}a\ (2t - 1)$. The distance traveled is the time, 1 second, multiplied by the average velocity $\frac{1}{2}a\ (2t - 1)$, or $d = 1a\ (2t - 1)$ where d is the distance traveled in any one second.

The three formulas for uniformly accelerated motion then are $v = at$; $S = \frac{1}{2}at^2$; $d = \frac{1}{2}a\ (2t - 1)$.

The best example of a constant force producing uniform acceleration in a body free from friction is gravity acting upon a freely falling body. Experiment has shown that the acceleration due to gravity differs a little in different parts of the earth but is about 32.2 feet, or 980 cms. per second each second. In working with falling bodies the formulas explained above are used; g is susbtituted for a and the formulas then become $S = \frac{1}{2}gt^2$; $v = gt$; $d = \frac{1}{2}g(2t - 1)$.

Problems

1. If a train pulling out of a station has an acceleration of $\frac{1}{2}$ foot per second, what velocity would it have at the end of 20 seconds? 1 minute? 2 minutes, 56 seconds? How many miles per hour is the last velocity? How far will the train travel the first second, first 20 seconds, first minute?

2. A train running 60 miles per hour has its brake set and slows down at the rate of two feet per second. How long will it take to stop it? How far will it go before stopping?

3. A stone falls from the top of a cliff in three seconds. How high is the cliff? With what velocity does the stone strike?

4. A man in a balloon drops a piece of iron and finds it takes 10 seconds to fall. How high is he?

5. If the building is 64 feet high, how long would it take a ball to fall to the ground if it should blow off the top?

6. How far will a freely falling body fall in 10 seconds?

The quantity of motion which a body possesses is often expressed as momentum, the product of mass times velocity. The momentum of a locomotive weighing 50 tons moving with a velocity of 20 feet per second is $100{,}000 \times 20 = 2{,}000{,}000$. The unit of momentum has never been named. In comparing momenta the same units of mass and velocity must be used.

We have found that motion can be changed in quantity or direction only by the action of force, and the second law of motion means that the change in momentum is proportional to the force. The change of momentum may be made the means of measuring the force applied. The unit of force depending upon this principle is called a dynamic unit. The force which will produce unit change of momentum in unit time is called the dyne in the metric system. That is, the force which acting for one second on a mass of one gram will give it a velocity of one centimeter per second is one dyne. The gravitational units of force, the gram weight and pound weight, that is, the pull of gravity for a mass of one gram or one pound have already become familiar and will be used except when it is necessary to have a unit which is absolute and independent of all variation. If a mass of one gram is let fall freely at this latitude it will receive an acceleration of 980 centimeters per second in each second. Since a dyne is a force which will accelerate a gram one centimeter per second every second, it follows that a gram is equal to 980 dynes at this latitude. Momentum equals mass times velocity. Change of momentum or force equals mass times rate of change of velocity or $f = ma$ where force is expressed in dynamic units. To change this to gravitational units, divide by g and we have $f = ma/g$. For gravitational units the author prefers to use $f = \frac{wa}{g}$ where w = weight in grams, a = acceleration in centi-

meters per second per second, and $g = 980$; or w = weight in pounds, a = acceleration in feet per second per second, and $g = 32.2$ in which case f = force in pounds. Substituting v/t for a, we have $f = \frac{wv}{gt}$ or w = weight in pounds, v = velocity in feet per second, t = time in seconds the force acts.

Problems

1. What force (neglecting friction) will be required to start a railway coach weighing 20 tons and give it an increase in speed of $\frac{1}{2}$ foot per second every second, on a level track. If friction adds 10 pounds per ton weight what total force must be exerted?

2. What force must be exerted on a 100-pound weight to give it an acceleration of 32.2 feet per second per second?

3. If a boy weighing 100 pounds stands on the platform of a set of scales placed in a passenger elevator what will his apparent weight be while the elevator is getting up speed at the rate of $1\frac{1}{2}$ feet per second each second, going up? going down? running at full speed without acceleration?

4. A 200-pound man stands in a street car while the motorman sets the brakes slowing down with a negative acceleration of 2 feet per second per second. What is the force required to keep him from being thrown forward? What force to brace him when the car starts up with an acceleration of 1 foot per second per second?

Gravity is the pull drawing the earth and any other body toward each other. Gravitation is a similar attraction existing between all bodies at a distance. Sir Isaac Newton watched an apple fall and asked himself why. If a one pound ball and a ten pound ball were tied together by a stretched rubber band and then left free to move, they would both move toward each other but not with equal acceleration. The momentum of each would be the same but the larger one receives only one-tenth as great a velocity as the smaller one. The same condition exists when an apple falls to the earth, the earth also falls toward the apple, and the momentum of each is the same. If your

mass was the same as that of the earth and you should fall down, the earth would fall half-way to meet you.

What the force of gravitation is no one knows, and no one knows how it acts between bodies. If a horse is to pull a load it is necessary to hitch him to it, but gravitation acts through a great distance and always keeps hold, yet the best scientists cannot tell us how. Newton was able to state some of the laws by which it acts: "The attraction between two bodies varies directly as the product of their masses, and inversely as the square of the distance between their centers of mass." The laws of weight are derived from this: — 1. The weight of a body varies directly as its mass at any given place. 2. The weight of a body above the surface of the earth varies inversely as the square of the distance between its center of gravity and the center of the earth. 3. Below the surface the weight varies directly as the distance from the center of the earth.

The center of gravity of a body is the same as the center of mass. It is the point at which the whole weight of the body may be considered as centered. If a brick be resting on a plain surface any attempt to overturn it raises the center of gravity and it falls back to place again. This is called *stable* equilibrium. A pyramid balanced on its apex is in such a position that any movement will lower its center of gravity and it will tend to fall farther. Such a body is in *unstable* equilibrium. The unsupported bicycle standing still is in unstable equilibrium. If a ball lying on a plain surface be rolled along, its center of gravity is neither raised nor lowered. This is *neutral* equilibrium.

If a body be fastened to a string and whirled so as to give it a circular motion, there will be a pull on the string which will be greater or less as the velocity is increased or diminished. If a body be revolved in a horizontal

plane so that the gravity will always be the same, we may consider that, according to the first law of motion, the body tends to move in a straight line and would so move unless some force causes a change in direction. If the string be cut, the force which pulled the body out of a straight line would be removed and it would move on in a straight line tangent to the circle. To compute the centrifugal force of a body use the formula $f = \frac{wv^2}{gr}$; $f =$ force, $w =$ weight, $v =$ velocity per second, $g =$ acceleration due to gravity, $r =$ radius of circle. If this formula be used for bodies revolving in a circle, it may be simplified to the following: $f = 0.00034\ wrn^2$ where $f =$ force in pounds, $w =$ weight in pounds, $r =$ radius of circle in feet, and $n =$ number of revolutions per minute. In computing the centrifugal force of a locomotive rounding a curve the first form is usually used. For computing the force tending to tear apart fly-wheels and pulleys, the latter form is used.

Problems

1. What centrifugal force must be exerted when a locomotive weighing 100 tons runs at 40 miles per hour around a curve of 1000 feet radius?

2. In the above problem plot the centrifugal force as a horizontal line and the weight as a vertical line and find how much the track must be banked in order to make the resultant perpendicular to the track. What effect on this parallelogram would result if the weight of the locomotive were one half as great?

Energy has been defined as the ability to do work. We may measure energy in the same engineering units used for work, that is, foot-pounds. A foot-pound of energy is the ability to do one foot-pound of work.

If a pound weight be lifted four feet, four foot-pounds of work are done on it and it has four foot-pounds of possible

energy called potential energy. When it is dropped this potential energy is transformed to energy of motion. Just as it strikes it has the four foot-pounds of energy stored up as energy of motion. This is called **Kinetic Energy.**

Kinetic energy is the energy of any body due to its motion. Such is the energy of the sledge, the trip hammer, etc. The work done in lifting a body is the weight times the distance $E = WS$. E = foot-pounds of work, W = weight, S = distance weight is lifted. If a body falls this potential energy is all transformed to kinetic energy and the energy in foot-pounds is WS.

But S $= \frac{1}{2}gt^2$ (Falling bodies) (1)

$V = gt$ (" ")

$\therefore$ $t = V/g$; squaring both sides of the equation $t^2 = V^2\ g^2$.

Substitute in (1) $S = \frac{1}{2}g\frac{V^2}{g^2} = V^2/2g$ but $E = WS$ and substituting the value of S we have: $E = WS = \frac{WV^2}{2g}$ foot-pounds.

E = energy in foot-pounds, W = weight in pounds,
V = velocity in feet per second,
g = acceleration of gravity

It makes no difference whether the velocity was acquired as a falling body or by the application of any force, the result is the same. We may use this formula then to find the foot-pounds of energy possessed by a base ball, cannon ball, trip hammer, locomotive, or any other moving body.

Problems

1. The Lake Shore Railroad uses a pile driver with a 1000-pound hammer lifting it 30 feet and letting it fall. How many foot-pounds of energy has it when it strikes? What kind of energy? Note two ways of working this problem, select the short method, and tell how to work it the other method.

2. If the pile is driven 3 feet at a blow, what is the force of the blow? If driven 2 feet? 1 foot? 6 inches? 3 inches? 2 inches? (The force of the blow multiplied by the distance the resistance is moved gives the foot-pounds of work done and this must equal the energy expended. If a hammer strikes a piece of iron will the force of the blow be the same with the iron on an anvil as it would be with the iron on a feather pillow?)

3. What is the energy of a 200-pound trip hammer moving 20 feet per second?

4. What is the energy of a 50-ton locomotive moving 20 feet per second? Moving 40 feet per second? What is the ratio of the last two results? Why is this?

5. Why does an automobile running into a stone wall have nine times as much energy to use in smashing itself if it is running at sixty miles per hour as when running 20 miles per hour?

If a heavy block, placed on a smooth table, be pulled along on the surface by a spring balance, it will be found that some force must be exerted to keep it moving. This is used in overcoming friction. If the block weighs ten pounds and has a flat face with 100 square inches area and an edge with only 10 square inches surface, the force to overcome friction is found to be the same whether the block is on the edge or on the face. This is approximately summed up by the statement that the friction depends upon the pressure and is independent of the size of the surface. It will vary with the nature of the substance and the nature of the surface. The friction is less when the body is in motion than when it is at rest. If the pressure between the two bodies is 10 pounds and one pound pull is required to keep one of them sliding on the other at a uniform speed, the coefficient of friction is one tenth. The force required to keep a body moving at a uniform velocity divided by the pressure is the coefficient of friction. The coefficient of friction of bronze on bronze, or bronze on cast iron when dry is about 0.2. The coefficient of friction for the same surface well lubricated is from 0.05 to 0.07.

Problems

1. What is inertia?

2. What are Newton's laws of motion?

3. If two forces act on a body at a certain point at one time, what is the resultant and how may it be found?

4. Describe, illustrate, and give a unit of each of the following: work, power, energy, momentum, force.

5. If a force of 500 pounds is pulling directly east on a body and a second force of 900 pounds is pulling south on the same body, what is the resultant force?

6. If a belt running over a pulley has a tension downward of 750 pounds, and the other side of the belt, running from the pulleys at an angle of 45 degrees to the vertical, has a tension of 250 pounds, find the direction and magnitude of the resultant pull on the hanger. If this belt is transmitting 20 horse-power, what speed must it have?

7. If a boat be rowed across a river at right angles to the current at 4 miles per hour, and the current carry it down at the rate of 2 miles per hour, find the actual velocity and direction.

8. What horse-power is required to raise a weight of 99,000 pounds a height of 40 feet in one half hour?

9. A cross head weighing 500 pounds, having bronze shoes, slides on a well-lubricated cast-iron surface. What is the total friction?

10. A locomotive weighing 40 tons has to exert a force of ten pounds per ton in overcoming friction when it is in motion. What total force must the locomotive exert to increase its speed 2 feet per second in one second? What will be the momentum of this locomotive when it is running 60 miles per hour? What will be the centrigufal force if it runs at the above speed around a curve with a radius of 2000 feet?

11. If the rim of a fly-wheel weighs 500 pounds, and has a diameter to the center of the rim of 8 feet, how large is the force tending to tear it apart when revolving 20 times per minute?

12. If a body will fall from the top of a building in 2 seconds, how high is the building in feet and in meters?

13. At one of the amusement parks, on a certain railroad, there is a stretch of track 60 feet long with a drop of 20 feet. If the car runs without friction down this incline, starting from rest, what velocity will it have? how many miles per hour is this? If it drops vertically 20 feet, what velocity will it attain?

If a heavy weight be suspended by a light cord as shown in Fig. 29 and pulled to one side of its lower point as in that figure, the forces of gravity and the string will result in the force causing the weight to move as shown; *a* is a line to represent the force of gravity, *B* the pull of the string, and *r* the resultant which is unbalanced and therefore produces motion. This was known before the time of Galileo, but it remained for that great observer to find that a pendulum always took approximately the same time for a swing, whether that swing was long or short, if the pendulum remained the same length. Galileo, sitting in a cathedral when the chandelier was set swinging, observed that when almost at rest, one swing or vibration took the same time that one vibration took when making a long swing. The distance or length from point of rest to one end of the swing is the **amplitude**. The amplitude is the length of the swing *from the position of rest* (see *AB* in the figure). The swing from one point back to the same point going in the same direction is a double vibration. The swing from one side to the other is a single vibration and is one-half a double vibration. The time of the pendulum is the time of a single vibration. If the time is one second, it is called a seconds pendulum. The laws of the pendulum are:

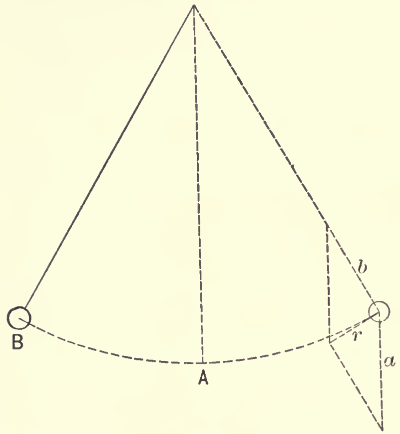


Fig. 29.

1. The time of the pendulum is very nearly independent of its amplitude, if the amplitude is only a small part of the arc of a circle.

2. The time of a pendulum is proportional to the square root of its length.

3. The time of a pendulum is inversely proportional to the square root of the acceleration due to gravity.

4. The time of a pendulum is independent of its mass.

These laws are expressed in the formula $t = \pi\sqrt{\frac{l}{g}}$;

t = time; l = length; g = acceleration due to gravity.

Solve this formula for g in terms of the other values. The chief use of the pendulum is to measure time.

Before the use of the pendulum became general the sun-dial and the sand hour-glass were used. Examine the escapement of a clock and see how the pendulum is applied. Substitute in the formula $t = 1$ and find the length of the seconds pendulum. Compare this with the master-clock in the office.

CHAPTER III

MECHANICS OF FLUIDS

THE most commonly accepted theory, that all matter is made up of molecules, has been mentioned in Chapter I. It is supposed that the spaces between the molecules are large compared to the size of the molecules, and that the particles themselves are therefore not in contact but are continually in motion and bounce against one another. If the molecules are fixed so that they vibrate in one place, the body will not change its form and is a solid. A solid is a body which retains a definite form and volume.

In some bodies the molecules are supposed to be free to move about from place to place and, as they strike one another and rebound, they move about from place to place. The body will not hold a definite form but will flow and take the shape of the containing vessel. Such a body is a liquid. A liquid is a body which takes the shape of the containing vessel but maintains a definite volume. At ordinary temperatures water and mercury are examples of liquids. In both of these cases the cohesion between the molecules holds them together so that they keep a fixed volume. In some bodies the molecules repel with a force greater than that of cohesion and the particles get as far apart as possible. Such a body will have no definite fixed volume but will expand until it is distributed throughout, or fills the containing vessel. Such a body is gas. Hydrogen, oxygen, and air are examples.

The three states of matter are solid, liquid, and gaseous. The last two are often combined and called fluid. The characteristic of a fluid is the ease with which its parts

slide over each other and it changes its shape, namely, its mobility, If at a certain temperature a body be part liquid and part gaseous, the latter part is not considered a gas but is called vapor. Many substances may exist in all three states of matter depending upon the condition of temperature. Water may be put in an ice box in the form of a solid. At ordinary temperatures it is a liquid while at higher temperatures it becomes steam, an invisible gas. At ordinary temperatures water exposed in an open vessel will slowly evaporate. It then takes the form of vapor.

A gas may be compressed. When a pneumatic tire is filled, several cubic feet of air may be compressed to one cubic foot. If the pressure is removed it will expand again. Liquids are almost incompressible, even under enormous pressures, and on the other hand when the pressure is removed they do not expand. Aside from this difference, liquids and gases may be treated much alike. This chapter is to present the mechanics of fluids.

In Fig. 30, suppose a and b are two cylinders of the same size, one fitted by a block of wood while the other is filled with water. Each is fitted with a piston, and suppose in each case the piston has an area of 50 square inches. Neglect the weight of piston, wood, water, etc., in each case, and suppose a force of 500 pounds is applied to each piston. This would be a pressure of 10 pounds to the square inch and in the case of b would be transmitted to the end of the cylinder and there exert a pressure

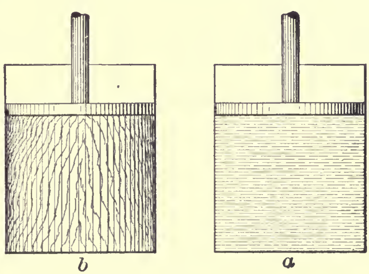


Fig. 30.

In b pressure on the bottom only.
In a pressure on the sides also.

equal to 10 pounds per square inch. In *a* there would be the same pressure of 10 pounds per square inch on the bottom of the cylinder, but since the molecules are free to move and slide over each other, they will press out on the sides of the cylinder and the pressure of 10 pounds per square inch will also be transmitted to the sides. If a pipe be tapped into the sides of *a* and a pressure gauge put on, it will be found that, neglecting the weight of the water, the pressure is the same at every inch of surface.

Every boy knows that the pressure applied to the water at a pumping station is transmitted through the pipes which make many turns and presses outward at any point. If a hole is made in the water pipe at any point, pressure will be required to keep the water in. Pascal summed this up in the following law: "The pressure per unit area exerted anywhere on a confined liquid is transmitted undiminished in all directions and acts with the same force on all surfaces at right angles to those surfaces." This principle is made use of in the hydraulic press.

In Fig. 31, *a* is a piston having a cross section of 1 square inch. When this is raised valve *f* opens and water flows in to fill its place. As *a* is pressed down, valve *f* closes and valve *c* opens allowing the water to flow into the large cylinder, and if *a* is pressed down with a force of one pound, this pressure will be transmitted to every square inch of area in the large piston *b*. If this has an

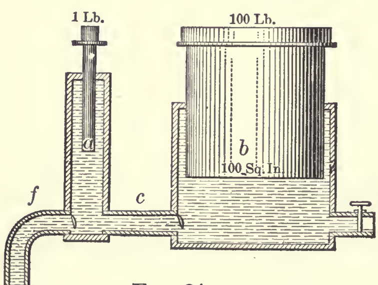


FIG. 31.

The pressure on the pistons is proportional to the area or in proportion to the square of the diameter.

area of 100 square inches the total pressure will be 100 pounds.

The small piston is usually worked by a lever and may have a pressure of 500 pounds per square inch in which case the large piston would receive a pressure of 500 pounds per square inch or a total force of 50,000 pounds.

It is evident that the lower part of a fluid must support the portions of the fluid that rest upon it. The weight due to gravity must cause pressure in the fluid. This pressure is transmitted in all directions. Suppose *a* and *b*, Fig. 32, are two cylinders of the same size at the bottom, connected by pipe *c*. If water is poured in until both are filled to near the top the water will stand at the same level in both. The fluid is at rest and the pressure at *c* is the same from each side or there would be a flow of water. If we consider a small particle of water at *f*, the pressure must be the same in opposite directions or the particle would move in the direction of the unbalanced force. At *d*, the water is exerting a downward pressure in the pipe *e*, and at the foot of the pipe the pressure is transmitted in all directions and presses up on the cylinder head the same amount that it presses up to support the water at the same level at *f* in *a*.

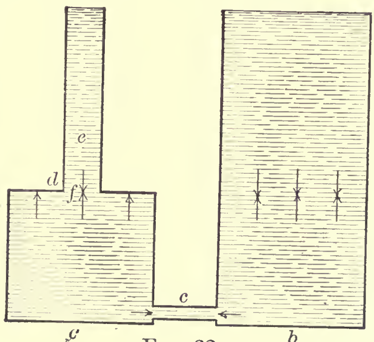


FIG. 32.

As the pressure is balanced at *c*, the pressure per square inch is the same in each cylinder and the pressure on the bottom of *a* is the same as the pressure of *b*. *In a*

fluid at rest, the pressure at any point is independent of the size and shape of the containing vessel but depends upon the depth of the fluid only. A dam 10 feet high and 50 feet long holding back the Atlantic ocean has the same pressure to withstand as a dam the same size forming part of the side of a salt water canal. If you suppose that the pressure depends upon the quantity of water present, rather than the depth, go home and watch the tea kettle boil and wonder why the great weight of water in the body of the kettle does not more than balance the small quantity in the spout and make it all run out.

In Fig. 32, *a* and *b* each have an area of one square foot, the total pressure is the same. The pressure is equal to the weight of the water in *b*. To find the force on a surface, multiply together the area of the surface, its depth, and the weight of unit volume of the liquid. A cubic foot of water weighs $62\frac{1}{2}$ pounds. A cubic centimeter weighs 1 gram.

If in Fig. 32 *a* has an area of one square foot and the depth is 10 feet, what is the force on *a* when the vessel is filled with water? What is the pressure per square inch? Find the same for *b*. Since there is so much more water pressing on *b* from where does the extra force on *a* come? If a hole were drilled in *d*, would the water run out? Why? Draw a diagram of a lawn hose attached to the bottom of a water-tower to show that pressure due to weight of fluid may be in any direction.

In a high-level water storage tank, suppose the level of the water to be 60 feet above the level of the first floor of your school building and a one-inch pipe to run from the storage tank to the level leading into a closed steel tank heater. What would be the pressure per square inch? Would it be any different if the storage tank extended down full size to the school level? A certain little town in

Michigan which had no water-works put in a town pump and put up a large tank, such as the railroads use, on posts the height of the second floor. A two-inch pipe ran from this to the street level and a hydrant was put in. They expected to attach a hose to the hydrant and the "great weight of water" in the tank would throw a stream over any three-story building in town. Did it work?

The plumber uses the approximate rule that there is a pressure of one pound per square inch for every two feet in depth of water. What is the error of this rule at a depth of 34 feet below the surface? A steam boiler must be tested to a pressure higher than the steam pressure it is to carry. If a new boiler is to be tested to a pressure of 500 pounds, would it be safe to fire up and run the steam pressure to 500 pounds? It is filled full of water and then a small force pump is attached and the pressure of 500 pounds per square inch is exerted in the force pump cylinder. What pressure is exerted in the boiler? Why? If it breaks, would there be an explosion? Why?

If a fish were 34 feet below the surface of the water, what pressure per square inch would he have to sustain? Why does this not crush him? Would the pressure vary if the fluid had less weight per cubic foot or more weight per cubic foot? Air is a fluid much lighter per cubic foot than water. The enormous quantity of air above the surface of the earth must exert a considerable pressure upon the earth. Did you ever notice this pressure? From the time of Adam until the time of Torricelli, men paid little attention to the pressure of the air. Before this time it had been observed that when a tube was placed with one end in water, as in Fig. 33, and the piston withdrawn, the water would follow it. It was also found that the water would follow about 34 feet and could not be raised any farther. Mercury is 13.6 times heavier than

water, and when mercury replaced the water it would rise to a height of only 29.9 inches.

Torricelli, in 1643, filled a glass tube more than 30 inches long with mercury. He then inverted it in a cup of mercury, as in Fig. 34. The mercury fell from the end of the tube and stood about 29.5 inches above that in the cup. He believed the mercury in the tube pressed down enough to equal the pressure of the air on the same area in the cup. To prove this he carried the tube up on a mountain and found the mercury in the tube settled down still lower. The space above the mercury containing nothing but a little mercury vapor is called a Torricellian vacuum. The pressure on the mercury surface in the cup is due to the weight of the air above it just as the pressure on the boy at the bottom of the heap in a foot ball game is due to the weight of the boys on top.

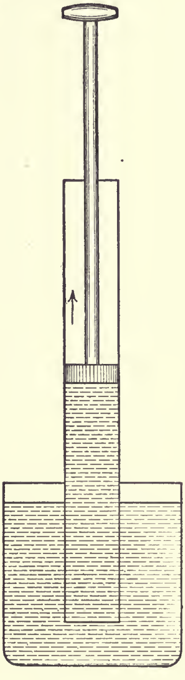


Fig. 33.

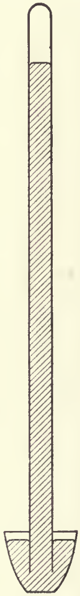


Fig. 34.

There is a popular impression that mercury rises in the barometer tube, or water under the piston, etc, because of suction. What is incorrectly called suction is due entirely to pressure outside. A simple demonstration of this is shown in Fig. 35. A barometer tube, or Torricellian tube, is placed inside a long air-tight guinea and feather tube. The mercury stands at about 29 inches. If this is placed on

the air pump and part of the air exhausted the mercury in the tube falls. This shows that pressure on the mercury in the open test tube, not suction, held the column of mercury up. If the air pump is a good one, the mercury will fall to almost the same level as that in the test tube.

The reading of a barometer depends upon the weight of the mercury and upon the pressure of the air. If the temperature of mercury is changed its density changes, hence to compare readings in different places the mercury must be at the same temperature. For convenience the freezing point $0°C$ is taken as normal temperature. If the mercury is warmer than this, it has expanded and a small quantity must be subtracted. The pressure of the air depends upon the layers of air above the instrument, so if

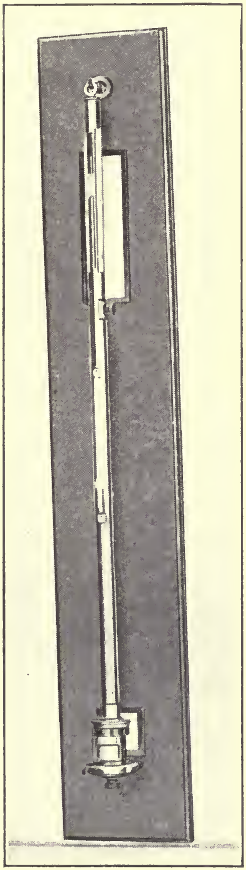


FIG. 36. — Standard U. S. Barometer.

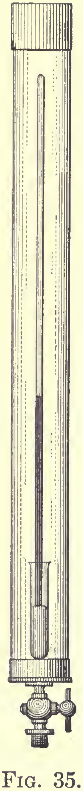


FIG. 35.

When air is removed from the large tube the mercury in the Torricellian tube falls, showing that the mercury is supported by pressure without, not by "suction."

the elevation is changed, the pressure is changed. Sea-level is taken as standard level, hence if the instrument is above sea-level a small quantity must be added to the reading. These are taken from tables and the correct reading is said to be reduced to sea-level. When readings taken in different places are compared, it is found that they differ. A line drawn on a map through places of equal pressure is called an isobaric line or an isobar. A region of low-pressure is called a low or cyclonic area. The air flows in from all directions toward such an area, forming a whirlpool of air. These cyclonic areas in the United States whirl counterclockwise. They are continually crossing the country from the west, following well defined paths, and the weather forecaster is able to predict the weather conditions for about 24 hours ahead, because of his knowledge of the action of these lows. The nearest United States weather bureau will furnish any school with weather maps. A series of them should be studied.

Problems

1. What is the force on the bottom of a vertical tank 34 feet deep and one foot square, filled with water? What is the pressure on each square inch of the bottom? Mercury is 13.6 times as heavy as water, how deep must a tank of mercury be to give the same pressure per square inch? What is the pressure in pounds per square inch when the barometer stands 30 inches?

2. In the condensing engine the degree of vacuum in the condensing chamber is expressed in pounds below atmosphere or in inches of mercury below atmosphere. On a day when the barometer stands at 30 inches and the condensing chamber is reduced to $\frac{1}{3}$ the pressure of the atmosphere the engineer calls it 20 inches of vacuum or 8.9 pounds vacuum. The pressure in the chamber would then be 10 inches or about 4.9 pounds per square inch. When the barometer stands at 29 inches what is the pressure inside in inches and the vacuum in pounds when the vacuum gauge reads 10 inches? 14 5 inches? 26 inches? 34 inches? Is the last one possible? Why?

In Fig. 37 is shown a lift pump, sometimes called a suction pump. The piston (*b*) is lifted by means of the pump handle and this removes the air pressure in the cylinder above the valve (*a*). The pressure below (*a*) raises that valve and the water runs into the cylinder. Notice that suction can never raise water. If the air pressure on the water outside of the pump were removed, the water would not flow through (*a*). Piston (*b*) is

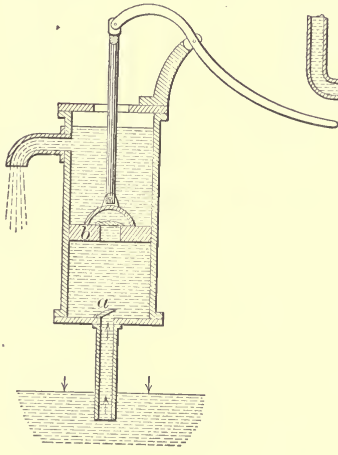


FIG. 37.

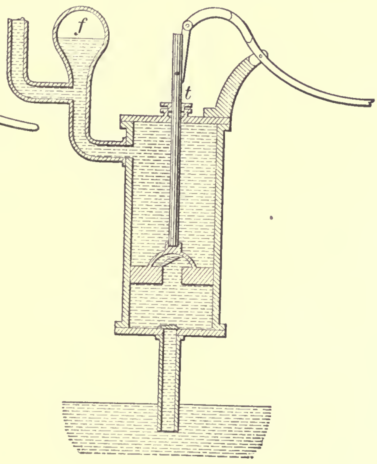


FIG. 38.

stopped and valve (*a*) closes, and as (*b*) is pushed down the water flows through *b*. The next stroke lifts it out of the cylinder. If suction pulled the water up, then there would be no limit to the height at which the cylinder could be placed above the water in the well. When the water barometer stands at 34 feet, the cylinder must be placed a little lower than that, as the valves cannot be made to work perfectly air-tight. Could a city pumping station be located more than 34 feet above the level of

a lake from which the water is drawn? Why? Air has no tenacity such as wire would have. The air is removed from many buildings by so-called "suction fans." If the air has no tenacity, why does the air rush into the stacks leading from a room to the fan when the fan is started. Suppose you were to pump mercury out of a well, how high could you place a cylinder above the mercury and still have it work?

The force pump in Fig. 38 fills its cylinder in the same way but the top of the cylinder is closed and packed at (*t*), and on the up stroke the water is forced into the air chamber (*f*). The air is compressed and its elastic tension forces the water out through the pipe in a steady flow.

In Fig. 39, the siphon is shown. So long as the siphon is empty no water will flow from the vessel (*b*). If the tube is filled with water it is evident that the air pressure is the same at (*b*) and at (*d*), but on the right between (*c*) and (*d*) the water column (*a*) is pressing down and its pressure is subtracted from that of the air. On the left, the water column (*h*) is pressing down and its pressure is subtracted from that of the air. The result is unequal at (*c*); there is an unbalanced pressure toward the longer column which pushes the water through the tube. If (*c*) were more than 34 feet above (*b*), the siphon would

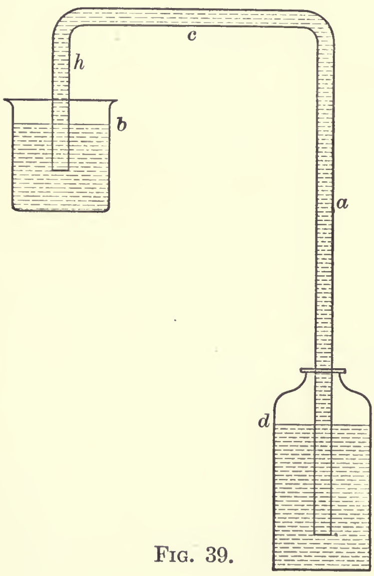


Fig. 39.

not work, as the air pressure would not lift the water to the bend in the tube.

In gases the molecules are supposed to be far apart and to move with great velocity. Each moves in a straight line until it collides with another molecule or with the wall of the containing vessel, when it rebounds in another direction. The path from one collision to another is the *Free Path*, and its length will depend upon the number of molecules in a given space and their velocity. It is supposed that the velocity of the hydrogen molecule, under normal pressure and temperature (N.T.P.) conditions, is about one mile per second. At the same temperature the oxygen molecule has only one fourth as great a velocity, but as its mass is 16 times as great it has the same kinetic energy. If a gas is confined in a cylinder with an air-tight piston working freely on one end, the molecules will continually strike this and rebound. There will be a pressure exerted against the piston. If the gas is compressed more molecules will strike the piston and the pressure is increased. This force, which the gas exerts in trying to expand, is its elastic tension. It is supposed that the number of molecules is very great and that their bombardment is continuous. When a cannon ball is forced out of a gun by the pressure of the expanding gases behind it, the molecules in bounding and rebounding must have an enormous velocity.

The pupils in any room are continually breathing out CO_2 into the room. This gas is heavier than air. If it were inert and the molecules not moving, it would all settle to the bottom of the room and remain as a distinct layer. Illuminating gas being lighter than air would rise to the top of the room, and there would be a layer of carbondioxide at the bottom, gas at the top, and air between. But the molecules of each gas are moving with

great velocity, and when they come to the edge of the gas many of them are carried on through and soon the gases are completely and uniformly mixed. This process is called diffusion. The lighter gases have the higher velocities, and hence diffuse more rapidly than the heavier ones. It is by the rate of diffusion that the molecular velocity is measured.

The molecule of oxygen weighs sixteen times that of hydrogen, and it is found that a cubic foot of oxygen weighs sixteen times as much as a cubic foot of hydrogen. This fact is sometimes used to explain the low barometer when the air contains a large amount of water vapor. The molecular weight of oxygen is 32; that of nitrogen is 28. Water (H_2O) has a molecular weight of only 18. If a cubic foot of gas at a given temperature and pressure always contains the same number of molecules, it is evident that if some of these are replaced by lighter ones the gas will not weigh so much per cubic foot. The effect will be the same as removing some of the heavy players from a football team and replacing them by lighter ones. The combined weight of the team will be less. When molecules of water vapor replace some of the oxygen and nitrogen, the pressure of the air will be less and the barometer will stand lower.

When solids go into the solution they disappear as visible solids. The molecules have become separated and move about in the solution much as gas molecules move about. Two solutions placed in contact will mingle by diffusion, as gases do. If two solutions are separated by membranes, it is found that the molecules will pass through and the solution will mix. This is osmosis. Two solutions will pass through at different rates. Many of the membranes of the body allow dissolved substances to pass through by osmosis. These are called semi-permeable

membranes. The semi-permeable membranes of the plant cells at the tips of roots allow water to pass into the plant and thus increase the pressure, helping the sap to rise to the top of the trees. Such pressure is osmotic pressure.

The molecular theory of gases would lead us to suppose that if pressure were applied to a gas the molecules would be crowded together and in a given volume there would be more molecules. If the pressure on a given quantity of gas were doubled, the gas would be compressed to one half its first volume and there would be twice as many molecules striking the same area in the containing vessel and the elastic tension would be doubled. This fact was discovered and experimentally proved by Robert Boyle and stated as Boyle's Law: "*At constant temperature the volume of a given quantity of gas is inversely proportional to the pressure upon it.*" If a cubic foot of air at atmospheric pressure is pumped into a bicycle tire so that the pressure becomes two atmospheres, that is, 15 pounds more than the atmosphere, the volume will be one-half a cubic foot.

Pressure gauges are made to read either in absolute pressure or in pounds pressure above that of the atmosphere. Absolute pressure is the pressure above zero. Steam pressure is usually given as the number of pounds above the atmospheric pressure. In the condensing engine a chamber is used in which the pressure is less than one atmosphere. Such a partial vacuum is measured by a vacuum gauge. The pressure of the atmosphere is about 29 inches of mercury. The vacuum gauge is so arranged that it reads, in inches of mercury, or in pounds the amount the pressure has been reduced below atmospheric pressure.

A common form of gauge is shown in Figs. 40 and 41.

The curved tube A, Fig. 40, is flattened slightly and

tends to straighten out, just as your garden hose does, when pressure is applied to the inside through the tap. This moves the pointer across the dial.

The air pump may be used for compressing air or for exhausting the air from a chamber and producing a vacuum. In the latter the piston and valves are arranged in a manner similar to those of the water pump already considered, except that in good pumps the valves are arranged to work mechanically as the pressure of the air soon becomes too small to work them. Suppose an air pump to be so constructed that the cylinder is one-third as large as the chamber from which the air is to be removed. As the piston is lifted, the air of the chamber expands to follow the piston; one-third is added to the volume, and the air expands from $\frac{3}{3}$ to $\frac{4}{3}$ its first volume. One-fourth of the air is therefore removed from the chamber. The next stroke removes one-fourth of the remainder. Therefore, after each stroke there remains in the receiver $\frac{3}{4}$ of the quantity present at the beginning of the stroke. After the tenth stroke therefore, there would remain $(\frac{3}{4})^{10}$ of the beginning quantity of gas. A little consideration will show that an air pump cannot produce a perfect vacuum. Examine the dash pot of a large Corliss Engine, and explain how the air pressure is made to close the cylinder valves quickly.

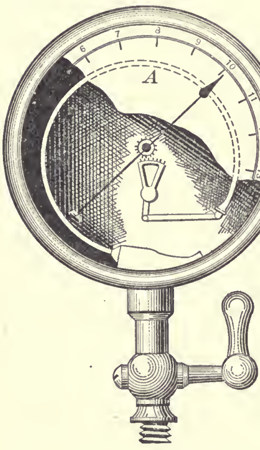


Fig. 40.

The curved tube A is flattened slightly and tends to straighten out, just as your garden hose does, when pressure is applied to the inside through the tap. This moves the pointer across the dial.

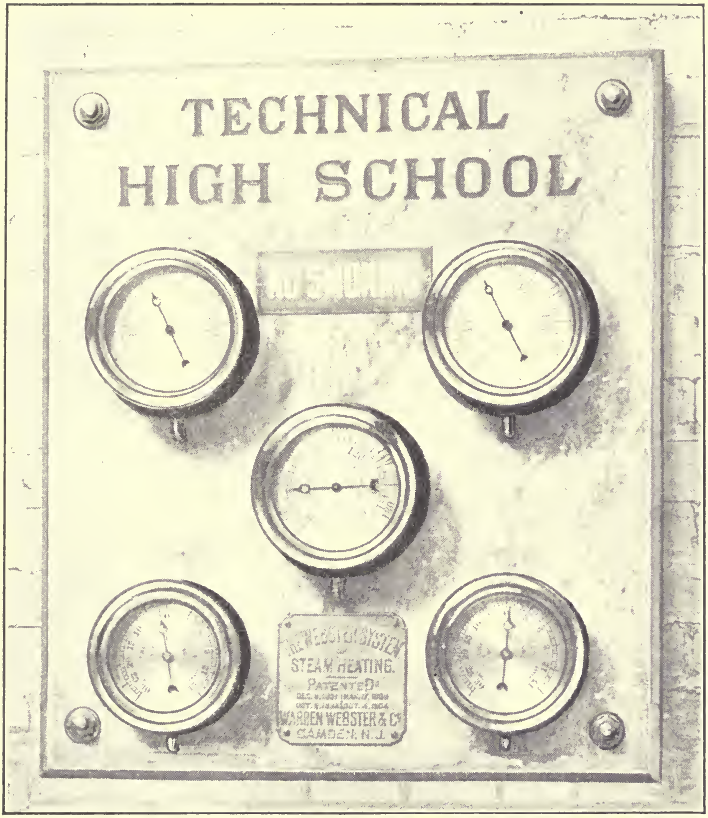


Fig. 41. — Pressure and Vacuum Gauges.

These read in pounds per square inch above or below the pressure of the atmosphere. The two lower dials read the pressure in the condensing chambers. Why does the vacuum scale run to 15 only?

At the surface of any liquid, a thin layer of molecules is under tension so that it acts like a thin elastic membrane stretched over the surface. It will be seen in Fig. 42 that a molecule at the center of a very small circle with its centre at the surface will be attracted by the molecules

near it in quadrants (*b*) and (*c*), and there will be no molecules in (*d*) and (*a*) to balance this force. Hence the surface will be stretched. This is called surface tension. A fine steel needle may be supported by the surface tension of water.

In Fig. 43, water is shown in contact with glass. Here in the circle drawn, a molecule of water near the glass is attracted by the glass in quadrants (*a*) and (*b*), which is greater than the attraction of the water in (*c*), and the

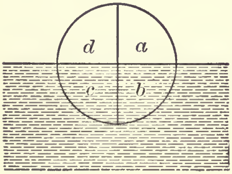


FIG. 42.

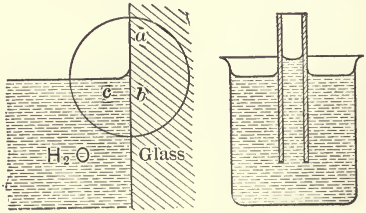


FIG. 43.

Water adheres to clean glass. If the glass be oiled what is the result?

surface of the water rises in a curve near the glass. If a small tube is used, as in Fig. 43, the water will rise in the glass tube.

If the tube is very small (a capillary tube), the water will rise a considerable height. The absorption of ink by a blotter or the rising of oil in the wick of a lamp are familiar examples of capillarity. If the attraction of the molecules of the liquid in the quadrant (*c*) is greater than that of the molecules in (*a*) and (*b*), as is the case with mercury and glass, the surface is depressed as in Fig. 44.

In Fig. 45, suppose a cube one foot on each edge be placed with its upper surface parallel to the surface of the water and two feet below it, the downward pressure on the upper surface would then be 125 pounds, and the

upward pressure on the lower surface would be 187.5. The difference between these two would be 62.5 pounds and is acting against gravity. The cube would appear to lose in weight by the amount of 62.5 pounds, an amount equal to the weight of a cube of water of the same size. This excess of upward pressure is called buoyancy. Archimedes stated the principle of buoyancy as follows: "*A body immersed in a fluid will lose in weight an amount equal to the weight of the fluid displaced.*"

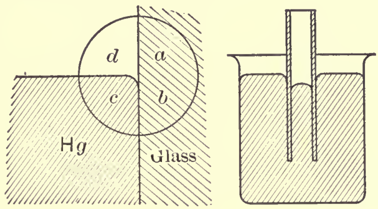


Fig. 44.

This principle of Archimedes applies also to any body in air; it is lifted or loses by an amount equal to the weight of air displaced. A sphere weighed in air and then in a vacuum will weigh more in the latter case. Suppose a pound of lead and a pound of feathers are each weighed in air and then weighed in a vacuum, would the weight be the same? Would a balloon rise in a vacuum? Why does a balloon rise to a certain height and then not go any higher. If a balloon be closed air-tight, why will it burst when it reaches a high altitude?

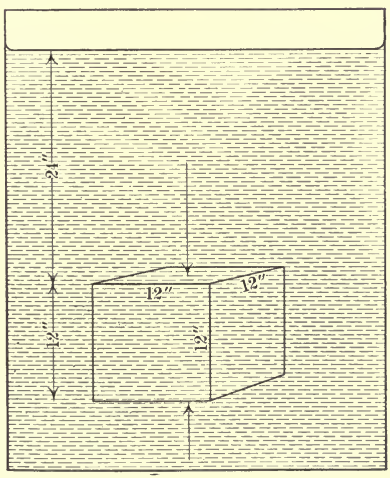


Fig. 45.

A body lighter than a fluid in which it is immersed will be lifted by a force equal to the weight displaced and will rise and float at the surface, displacing fluid equal to its weight. How many cubic feet of water will a 500-ton ship displace? Why does a row boat sink deeper into the water when a person steps into it? If the person weighs 151.5 pounds, how much water will the boat displace due to his being in it? Why will a good egg sink in fresh water and float in salt water?

The specific gravity of a body is the ratio between its weight and the weight of an equal volume of water. If the cube in Fig. 20 were cast-iron, it would weigh 450 pounds when weighed in air. Weighed in water the weight would be 387.5; the loss of weight is 62.5 pounds. The specific gravity then is 450 ÷ 62.5 or 7.2.

In using the metric system it is customary to use the term density instead of specific gravity. Density is the quantity of matter per unit volume usually expressed in grams per cubic centimeter. The gram is the weight of one cubic centimeter of water. Hence, if we take one cubic centimeter of cast-iron, which is 7.2 times as heavy as water, it will weigh 7.2 grams. Specific gravity and density in the metric system are numerically the same. The specific gravity of a few substances is given in the following table.

The density of most substances will vary in different samples and will differ somewhat from these figures.

Substance	Specific gravity or density per cu. cm.	Weight, pounds per cubic foot.
Ash (dry)	0.70	43.7
Ash (green)	0.84	52.8
Acetic Acid	1.062	66.4
Alcohol	0.80	50.
Aluminium	2.65	165.6

Beech	0.69 to .852	53.2
Cedar	0.561	35.
Cork	0.24	15.
Copper (cast)	8.81	550.6
Copper (sheet)	8.88	555.
Brass	8.38 to 8.44	527.5
Gold	19.50	1218.8
Hydrochloric acid	1.22	75.2
Iron (wrought)	7.68 to 7.78	
Iron (cast)	7.20 to 7.24	449.
Lead	11.36	709.7
Lignum Vitæ	1.33	83.3
Maple	0.75	46.
Mercury	13.6	850.
Milk	1.032	64.5
Nitric Acid	1.22 to 1.56	
Oak	0.85 to 1.17	
Pine	0.46 to 0.60	
Platinum	21.5	1348.8
Sea water (about)	1.03	64.4
Silver	10.5	656.3
Spruce	0.5	31.2
Steel	7.84	490.
Sulphuric acid	1.84	115.1
Tin (cast)	7.29	455.8
Walnut	0.67	41.6
Water	1.00	62.5
Zinc (cast)	6.9	431.3

The principle of Archimedes furnishes an easy method of finding the specific gravity of a solid which is insoluble in water. The body is weighed in air and then in water. As a body loses in weight, an amount equal to the weight of water is displaced, and the loss is the weight of an equal amount of water. Divide the weight in air by the loss of weight in water and the result is the specific gravity. If the solid be lighter than water, a sinker is tied on to submerge it. Explain the mathematics in this case. The specific gravity or density of a solid may be found if its

shape is such that its volume can be measured by getting its volume in cubic centimeters and dividing the weight in grams by the volume in cubic centimeters. Why is this equal to the specific gravity?

The specific gravity of a liquid may be found by filling a bottle with water and weighing it, then with a given liquid and weighing it again. The weight of the liquid divided by the weight of the same volume of water gives the specific gravity.

The hydrometer is a glass tube terminating at its lower end in a bulb filled with shot or mercury to cause the tube to float in a vertical position. A floating body displaces a weight of liquid equal to its own weight. If the hydrometer is placed in water it will sink to some certain point; this point is marked 1. If it be placed in a lighter liquid it will have to sink deeper to displace its weight. A scale is marked on the tube so that when placed in any liquid, the mark at the surface of the liquid indicates the specific gravity.

Problems

1. Explain the principle on which the so-called suction pump acts.
2. Explain the action of a siphon.
3. Can a perfect vacuum be produced with an air pump?
4. In what respects is the pressure of the atmosphere similar to the pressure of a liquid?
5. How high a column of liquid, whose specific gravity is 2, will the pressure of the atmosphere support?
6. How is the pressure of the atmosphere measured?
7. How is the degree of a vacuum in a vessel measured?
8. An oak timber is $4'' \times 6'' \times 12'$. What is its weight? If floating on water, what portion of its volume will be submerged?
9. A barge 12 feet wide and 30 feet long with vertical sides is floating in fresh water. An elephant is led onto the barge, and when all is still it is found that the barge has settled 2 inches deeper than it was before. How much does the elephant weigh?
10. An irregular casting weighs, in air, 1047.6 pounds, and in water,

922.6 pounds. What is its volume? What is its specific gravity? What kind of metal is it?

11. Will a piece of solid steel float on water? Will a steel boat float on water? Will a piece of solid steel float on mercury? Why?

12. A vat in the shape of a cube 3 feet on an edge is filled with mercury. What is the total pressure on the bottom and the total pressure on one side?

13. When the barometer stands at 30 inches, what is the pressure of the atmosphere per square inch, when the barometer is 28.9 inches?

14. In making the casting for the base of a dynamo, the top of the riser is 24 inches above the base of the casting. When first poured, what is the pressure per square inch at the action of the casting. If in the above problem the riser has a height of 12 inches above a given point of the top of a casting and the specific gravity of sand is 1.8 what pressure per square inch must be applied to the surface of the sand to keep it from lifting or "blowing"? Work this problem mentally, getting only the approximate result by the method used in the foundry.

CHAPTER IV

STRENGTH OF MATERIALS

Elasticity has been defined as the resistance a body offers to change its shape or volume, or the tendency a body has to return to its original shape after being distorted. If distorted beyond a certain point a body will take a permanent "set," that is, fail to return to its first form. This point is called the elastic limit. A force tending to produce change of form or volume in a body is a stress. Any resulting distortion which takes place is a strain. Within the elastic limit the strain is proportional to the stress. In designing machines, bridges, buildings, etc., it becomes necessary to know the strength of the materials used, up to the elastic limit, and to make them of such a size and shape that the greatest stress they will ever be subjected to will not produce a strain coming anywhere near to the elastic limit. If a given rod in a bridge must support a given pull when the bridge is carrying its greatest load, the rod is usually large enough and of such material that the stress will not exceed one-fourth or one-fifth of the stress which would strain it to the elastic limit. This is said to give a "safety" factor of four or five.

The term "stress" is here used to mean the total force causing the distortion, not the more specific meaning of the term, namely, force per unit area. In the same way the word strain is used to denote the total distortion.

Stresses are classified according to the kind of strain they produce, as follows: tensile or pulling stress; trans-

verse or bending stress; compression or pushing stress; shearing or cutting stress; tortional or twisting stress. A wire carrying a load is under tensile stress, a column supporting part of a building is under compression. The piston rod of an engine is alternately under tension and compression. The rod used to turn the head of a jack-screw is under bending stress. A rivet holding together the plates of a boiler or the crank pin in an engine are subject to shearing stress. The shaft transmitting power in a shop is under tortional stress.

The tensile strength of any material is the resistance it offers to being torn apart. The tensile strength of any body is proportional to its minimum cross section. To find the tensile strength of any body it is necessary to know its tensile strength per square unit area and multiply this by the area of the smallest cross section of the body. The tensile strength of such metals as iron depends upon the treatment they have received. Samples of metals to be tested are placed in machines capable of pulling the samples apart and arranged to measure the stress at which the samples break. This is called the ultimate strength or the breaking stress, and when divided by the cross section of the samples gives the breaking stress per unit cross section. Tables giving the ultimate strength or breaking stress per square inch for the common materials will be found in any engineering hand book.

If the load is to be repeatedly applied suddenly the usual engineering practice is to use a safety factor of about 10. An example of such loading is the piston rod of a reciprocating engine. If the variations in load are to be gradually applied, 5 is usually considered a safe factor. The ultimate tensile strength of a few metals in pounds per square inch is as follows. It must be remembered that great variation is found in different samples.

Breaking stress in thousand pounds per square inch

Brass cast	15 to 20
Copper	20 to 30
Iron cast	15 to 20
Iron wrought	40 to 50
Steel axle	70 to 90
Steel machine	50 to 75
Steel tool	90 to 150
Steel Vanadium	100 to 200

What force will probably be required to pull apart a 3-inch rod of soft steel? What size machine steel rod will be required to carry safely a gradually applied load of ten tons?

In the case of chains the form of the links has much to do with the load the chain will lift before breaking. The Lufkins Iron and Steel Co. publish tables giving the breaking stress for their chains in pounds for each size rod used in making the links from $\frac{3}{16}$ to 3 inches.

The shearing strength of any body is the resistance it offers to being cut in two. Fig. 46 shows a body subject

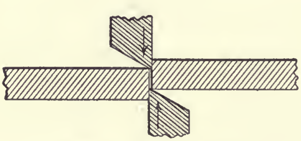


FIG. 46. — Single Shear.

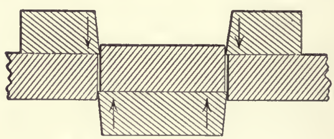


FIG. 47. — Double Shear.

to a single shear. Fig. 47 shows a body subject to a double shear. The ultimate shearing strength is proportional to the cross section. Under most circumstances the stress required to shear a body in double shear is twice that required to shear a body in a single shear. But it has been found by experiment that iron and steel rivets will give way under double shear at about 1.8 times their ultimate strength in single shear.

In case wood is subjected to shear, the force required

to cut it will be much less if the stress is applied parallel to the grain than if it is applied across it.

The average shearing strength of a few materials, in pounds per square inch cross section, follows. In determining the cross section needed to carry a given load, or in finding what safe load a body of a given cross section will carry, use a safety factor of 10 if the load is to be repeatedly applied suddenly, or a safety factor of four or five if the load is to be gradually applied.

Shearing strength in thousand pounds per square inch

Iron cast	16 to 30
Iron wrought	40 to 60
Iron rivets	30 to 50
Oak (parallel to grain)	500 to 800 pounds
Oak (across the grain)°	4 to 6 thousand
Steel	40 to 80

In the forge shop is a machine for cutting off bar iron. The hand lever has a force arm of 6 feet and a weight arm of 3 inches. This operates the cutting arm with a force arm of two feet and a weight arm of 3 inches. What force must be applied to shear a $\frac{5}{16}$ square bar of wrought iron? If the cutting arm swings on a $\frac{3}{4}$-inch bolt of wrought iron in double shear, how large a bar would it be safe to cut with the machine?

The crushing strength of materials is the resistance to a force tending to compress it. If the length of a column is not greater than five times its diameter or its least thickness when rectangular, it is called a short column. For such a column the crushing strength resists compression only. If the length is greater than five times the least diameter, we have compression and bending combined.

If the ultimate crushing strength of brick be taken at

800 pounds per square inch, what load will a brick foundation 8 inches square carry with safety factor of six?

For a long column (one from 5 to 40 times as long as its least diameter) the compression strength combined with the bending will depend upon the shape of the cross section as well as its size. A constant depending upon the shape of the cross section must be used with the above values. Such constants determined by experiment for solid round and rectangular, hollow round and rectangular, angle, cross, and T beams will be found in any engineering hand book.

Transverse strength of materials is the resistance the material offers to being broken by bending.

If a beam or rod is rigidly supported at one end and free at the other it is called cantilever. The rod used to turn the head of a jack-screw would be considered cantilever.

It will be remembered that the force applied is the stress, while the amount of distortion is the strain. The architect or the machinist sometimes meets the problem of transverse strength in a form which requires him to compute what size rod or beam will be required to carry a given load without the resulting strain exceeding a specified amount: sometimes he is required to find what safe working load a beam will support.

It has been found that if a beam is supported at the ends and loaded in the middle the strain is proportional to the load and to the cube of the length and inversely proportional to the breadth and to the cube of the depth.

That is $$S = k\frac{Wl^3}{d^3b}$$

As indicated in Fig. 48, w = load, l = length between supports, d = depth, b = breadth of beam, and k = a constant which depends upon the material used and must

be determined by experiments; s = bend or displacement.

If a beam of a given size is found to bend one-eighth of an inch with a certain load it will, if everything else remains the same, bend one-quarter inch under twice the load. If the load remains the same as the first, while the breadth be doubled, it will bend only one-half as much or one-sixteenth inch, while if the depth be doubled it will bend only one-eighth as much or one sixty-fourth inch. If the length or clear span be doubled, the bend will be eight times as much.

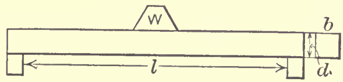


FIG. 48.

Beam supported at the ends and loaded at the center. How else may the load be placed? The formula explains why floor joists are placed on edge.

The value of a constant for a given material is determined by experiment. If W is given in pounds, deflection or bend in inches, span in feet, breadth and depth in inches, the following constants are given in the engineering table by Troutwine.*

Oak	.00023
Hickory	.00016
White pine	.00032
Cast-iron	.000027

How much will an oak beam 8×8 inches resting on supports 6 feet apart bend under a load of 2000 pounds at its center? In building practice it is considered that a beam should not bend more than $\frac{1}{40}$ inch per foot of length.

* For other values the reader is referred to Troutwine's Handbook for 1908, page 484.

Problems

1. Why is the rod of a tension member in a bridge truss "upset" before the thread is cut?

2. What load will probably be required to break a 1-inch round rod of wrought-iron?

3. What load will be required to crush a short rod of machine steel 1 inch in diameter? If a groove $\frac{1}{8}$ inch deep is cut around the rod, what load will be required to crush it?

4. The screw of a jack-screw is $\frac{3}{4}$ inch in diameter, 8 pitch, square thread, and made of machine steel.

If the crushing strength of machinery steel is taken as 60,000 pounds per square inch and its shearing strength is 52,000 pounds per square inch, what must be the length of the thread on the screw in order that it may sustain the full crushing load of the steel?

5. What is the maximum load such a screw will sustain?

6. On what diameter do you base the figures for crushing and shearing strength? Why?

7. If the shearing strength of cast-iron is taken as 16,000 pounds per square inch, what must be the length of the thread in the base in order that it may sustain the full crushing load of steel?

8. On what diameter do you base the figure? Why?

Note. The shearing area in the above need not be figured on the incline of the thread.

9. At a radius of 6 inches, how much force must be applied to the lever in order to raise the full load, supposing that 50% of the power is lost in friction?

10. What load will such a jack raise if the thread in the cast-iron base is $\frac{3}{4}$ inch long?

11. What proportions would you recommend for a jack-screw that is to raise twenty-five tons? Why?

CHAPTER V

SOUND

If a person in a boat in the middle of a pond drops a stone into the water, a series of waves is started which will spread in circles until it reaches the edge or dies out. If a series of chips are placed on the water they will be caused to dance up and down but will not be carried forward. The particles of water, that is, the molecules, dance up and down in the same way and are not carried forward. The same thing may be seen in a field of ripening wheat on a windy day. A wave starts at one side of the field and moves across to the other side. Any one head of wheat moves back and forth, yet the wave motion moves forward. Suppose an elastic ball, capable of expanding and contracting, were fastened in the middle of this room by elastic strings running out in every direction to all sides and edges of the room and all stretched. If the ball were suddenly to expand, an impulse would be sent out in every direction to the sides of the room. When it contracted, an impulse in the opposite direction would be sent out in all directions. This is a wave motion, and the front of any wave will be the surface of the sphere. *A wave motion or vibration of the frequency* (number per second) *which will be received by the ear, is sound.*

For the transmission of sound the student will readily recognize that three things are necessary, a vibrating body to start the disturbance, some substance in which the wave motion may travel, and a receiving instrument capable of detecting the waves or vibrations.

If one end of a rope be held in the hand and given a sudden jerk sidewise, it will be set into vibration. These vibrations will be at right angles to the length of the rope and will, for that reason, be called transverse vibrations. In the case of the rubber bands holding the ball, the vibrations were parallel to the length of the band and hence would be called longitudinal vibrations. In case of air vibrating, the air has no tensile strength to hold it together; hence there can be no transverse vibration, as one molecule would not pull the next one after it. A vibration in air is set up when a few molecules are pressed forward and crowded against the next ones. This compresses the air at one point, and its elasticity causes the molecules in the front of the disturbance to leap forward and those in the rear to rebound. At a given point in the air we would have molecules crowded together and then separated more than the average or a condensation or rarefaction, and these would move forward as the waves in the water did and we would have a wave motion. The frequency is the number of vibrations per second, and the wave length is the distance from a point on one wave to the corresponding point on the next wave.

As a wave moves forward by the successive crowding of the molecules, we would expect to find that it took time for a disturbance to travel a given distance. This is confirmed by the experience of every one who has had his eyes open at all. If you have watched a train at some distance you have noticed that the escaping steam can be seen before the sound of the whistle is heard. The flash of a gun will be seen before the sound of the report is heard.

This is because it takes the sound some time to travel the distance between the gun and the ear. The velocity of the sound has been measured by several methods and it is found to be about 1087 feet or 331.4 meters per second

at 0° C., that is 32° F. It is found that the velocity varies directly as the square root of the elasticity, and inversely as the square root of the density of the medium in which the wave moves. Since oxygen is 16 times as dense as hydrogen, at the same temperature and pressure the velocity of sound will be four times as great in hydrogen as in oxygen. Temperature changes produce changes both in elasticity and density of air, and therefore in velocity of sound. A rise in temperature of 1° C. increases the velocity of sound .6 meter or about 2 feet per second. What would be the velocity at 20° C.? $2 \times 20 = 40$ feet increase.

$$1087 + 40 = 1127 \text{ feet velocity.}$$

Suppose a bell is vibrating 256 times per second. When it has been vibrating for one second when the velocity is 1087 feet per second, the first wave sent out would be 1087 feet from the bell, and between that point and the bell the whole 256 waves will be found. If it were possible to take a snapshot of the series, we would have 256 waves arranged in order. The length of one of these waves will be $1087 \div 256$ or 4.24 feet. A little consideration will make it evident that if N = frequency, l = wave length and v = velocity in feet per second, $V = Nl$.

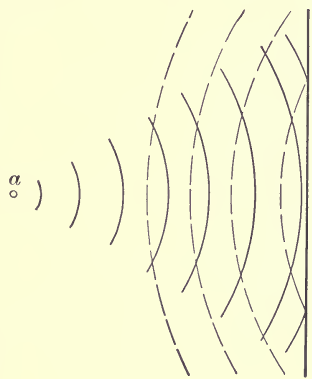


Fig. 49.

Sound from point (a) striking a surface is reflected and seems to come from a center beyond the reflecting surface. The echo from a wall or the echo in the forest are examples.

When a wave strikes a flat surface it is reflected as in Fig. 49 and appears to come from a new center. This reflected

sound is an echo. If the echo of a gunshot is heard in five seconds when reflected from a cliff, how far away is the cliff, temperature being 20° C.?

If a tuning fork vibrating with a given frequency be held above an air column whose length can be changed, as in Fig. 50, and then the length can be adjusted so that, while the fork is vibrating from (*a*) to (*b*), the condensation started at the fork downward from (*a*) has time to travel down to (*c*) and back to (*b*) exactly as the fork is ready to start back from (*b*) to (*a*), we will have the reflected condensation and the condensation of the fork together, and the sound will be very loud. The movement of the fork from (*a*) to (*b*) is one-half a vibration; if the condensations are to occur at the same time, the distance from (*a*) to (*c*) and back to (*a*) must be one-half a wave-length in air; that is, the length of the air column must be one-quarter wave-length.

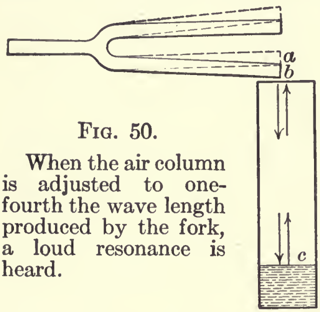


Fig. 50.

When the air column is adjusted to one-fourth the wave length produced by the fork, a loud resonance is heard.

If the length of the air column be increased by one-half a wave-length in air, the reflected wave will come back one and one-half-waves behind the fork and will again strengthen the sound. When a vibration is reinforced in this way, it is called resonance. The air column is called a resonating air column. This principle is taken advantage of in many musical instruments as will be seen when the student studies them. Perhaps the best example is the pipe organ.

Exactly the opposite of resonance will happen if two sounds be produced so that one tends to produce a condensation at the same time the other tends to produce a

rare faction. Then the two will strike a given particle of air at the same time and no movement will take place. One will destroy the effect of the other or interfere with it; hence interference takes place. This may be illustrated by slowly revolving the fork arranged before the resonating tube, as in Fig. 50.

Sound waves, as we have shown, are longitudinal, but for convenience they may be represented as in Fig. 51. Let the full line represent one wave series and the dotted line represent a second one, starting both, as at a, but of different frequency. Then if they start together or in the *same phase*, that is, the same part of the wave at the same

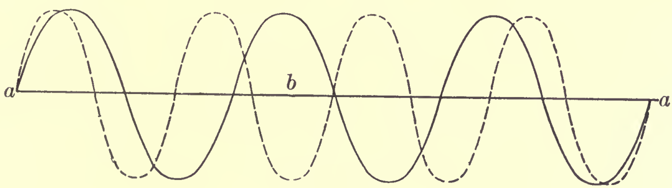


Fig. 51.

time, one will gain on the other and soon we will find them as at b, exactly opposite each other, that is, in opposite phase, so that one tends to produce a rarefaction at the same time that the other tends to produce condensation. The result would be mutual destruction or no sound at all. This is called interference. A little later we will find them as at d, where one has gained a complete vibration on the other and both are in the same phase, that is, both tend to produce condensation at the same time and place. The result is a condensation which effects the ear very strongly and the sound seems loud. The combined sound is first loud and then less so, the loud stages being called *beats*.

When a pendulum is vibrating, the distance from its

point of rest to one end of its swing is its amplitude. When a bell or string or other sounding body is vibrating, if its amplitude is small, it strikes the air with little force and the amplitude of each particle of air is small; while, if it is set in motion with a greater amplitude, it strikes the air with more force and the air is more strongly effected. The latter sound is louder than the first; *loudness depends upon the amplitude of vibration.*

A pendulum has a fixed time of vibrating which is independent of the amplitude. The same thing is nearly true of any vibrating body, such as a bell, a tuning fork, a plate, or wire.

Most vibrations have a definite frequency. It is well known that if a vibrating wire is tightened so as to increase its frequency, the sound will be of a higher pitch. Pitch depends upon frequency.

If a sound contains a mixture of a lot of vibrations of different frequency some of which are not periodic, it is called a noise. Such would result from clapping the hands or stamping the feet. If the vibration is regular, or periodic, the sound is a musical tone.

We have noted that the pitch of a tone depends upon the frequency or number of vibrations per second. The ratio of the frequencies of two tones is called a musical interval. If the ratio is 1, the tones are in unison: $\frac{3}{2}$, a fifth; $\frac{4}{3}$, a fourth; $\frac{5}{4}$, major third; $\frac{25}{24}$, a half tone; 2, an octave. Four tones whose frequencies are in the ratio of 4, 5, 6, 8, are a major cord.

Probably every student is familiar with the diatonic scale, a series of eight notes known as do, re, mi, fa, sol, la, si, do. The first one (do) may start with any frequency. The others have a fixed ratio to its frequency. The physicist starts with a key note of 256. There are several musical standards at present. The most common one is the

international pitch, using a key note, C, of 261 vibrations. The following table will show how the scale is built up.

The tempered scale, while of great importance in music, is omitted here, as other things seem to have a stronger claim on the time of the student in a one-year course of physics in a secondary school.

SCALE

Number . . .	1	2	3	4	5	6	7	8
Letter	C	D	E	F	G	A	B	C
Name	do	re	me	fa	sol	la	si	do
Ratio	1C	9/8C	5/4C	4/3C	3/2C	5/3C	15/8C	2C
1st octave .	256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512
2nd octave .	512	576	640	$682\frac{2}{3}$	768	$853\frac{1}{3}$	960	1024
Interval . . .	9/8	10/9	16/15	9/8	10/9	9/8	16/15	

We have now discussed loudness and pitch and must consider one other important characteristic of sound — quality. If the organ pipe is blown gently, its column of air will be set vibrating as one unit, that is, in one segment. The tone which will be the lowest that pipe ever produces, is called its fundamental tone. If blown a little harder, a much higher pitch will be given. This is due to the air column being broken up into segments and caused to vibrate in parts instead of a whole. By blowing carefully, the air in the pipe may be set in motion so that it produces both tones at the same time and both may be readily detected by the ear. The sound given out when both are produced is very different from either one alone. It is said to have different quality. The higher tone is an over-tone. The quality of a tone depends upon the over-tones present. Certain over-tones produce, with a fundamental, pleasant effect on the ear and give a rich, full tone, while some are unpleasant and discordant. The same note C sounded on the organ, the flute, the violin,

and the piano are of the same frequency, but the different over-tones in them give them a very different quality or timber. Helmholtz analyzed sounds, and then, by striking tuning-forks, produced all the same over-tones found in a given note; in this way he could reproduce or imitate the tones of different instruments so closely that he could deceive the ear.

The wire as a vibrating body is used in so many musical instruments that it is well to understand the laws governing the vibration frequency of stretched wires. It is found by experiment that if a wire is vibrated, either by a violin bow or by plucking it with the fingers, it gives out a certain tone, and if the middle point is held so that each half vibrates as a half length, the pitch will be the octave of the first tone, that is, the frequency is doubled. It is found that if the tension remains constant the vibration frequency is inversely proportional to the length. If a wire under a fixed tension sounds middle C (256) when its length is 60 cm., what length must it be to sound G (384)? The tension and length remaining constant, the vibration number varies inversely as the diameter. The length and diameter being constant, the vibration number varies directly as the square root of the tension.

An interesting application of sound vibration is found in the talking machine. There are several on the market, but all work on the same principle as the first one invented by Thomas A. Edison. A cylinder or disk of wax is revolved while a sharp needle point carried on a thin flexible steel plate scratches its surface. Any sound collected in the funnel will set the plate vibrating and the needle will trace these vibrations in the wax. The cylinder is moved forward by means of a screw, so that a helix is traced its entire length. A needle with a blunt point is substituted in place of the sharp one and the cylinder is turned again.

This time the hills and hollows in the wax will cause the needle and the steel diaphragm to vibrate exactly as it did before, and the sound will be reproduced so accurately that even a dog will recognize his master's voice. It was said of the Chicago Stock Yards that they saved every part of the pig but the squeal; now they pickle the squeal and hand it out at the five-cent theaters.

Problems

1. What is the length of the sound wave in air produced by a tuning fork vibrating 320 times per second, the temperature being 20°?

2. If a bell be struck by a hammer the sound gradually dies away. Explain.

3. Why is the pitch of a sound produced by a phonograph raised by increasing the speed of the cylinder?

4. A siren has 24 holes in the disk and makes 1000 revolutions per minute. What is the frequency of the tone?

5. A string stretched by a force of 25 pounds sounds the note E. What tension must it have to sound the C below?

6. What are the three characteristics of sound?

7. What law of strings does the violin player follow with his left hand?

8. Will the pitch of an organ pipe be raised or lowered by a rise in temperature? Of a piano?

CHAPTER VI

LIGHT

The universal law — that every particle of matter in the universe attracts every other particle in the universe with a force inversely proportional to the square of the distance between their centers and directly proportional to the product of their masses — enables us to compute the force of gravitation between any two bodies. Beyond this law, stated in a single sentence, how much does man know about the force of gravity?

The earth is held to the sun by an enormous force. What are the invisible bands holding the earth with the strength of steel and yet perfectly elastic? Is the force a pull from the front or a push from behind? How long does it take this force to reach out to the earth and harness it to the solar system? Has the action of this force a definite speed or is it instantaneous? The earth attracts an iron casting with the same force, whether or not air, wood, or any other known substance is between them. Are there any substances which would cut off gravity? Up to the present time we know almost nothing about this most common force. What little we do know about gravitation was discovered and announced by Sir Isaac Newton.

Newton also spent much time in investigating light. At the time he lived, about as much was known of it as is now known about gravitation. Newton asked the question, "What is light?" "How fast does it move?" "How does it travel from one point to another?" Al-

though Newton made the first observations which finally led to the discovery of the nature of light, he thought that it consisted of small white particles, which he called corpuscles, thrown out by some body, such as the sun, and flying through space until some of them came in contact with the eye and enabled one to see.

We harness Niagara Falls and develop electric power to light and turn the wheels of several cities. Coal comes from plants which lived thousands of years ago. Plants will grow only in sunlight; this is stored up energy, and, whether in coal or in water, power comes from the sun. If on a clear day a surface is held up at right angles to the sun's rays, it receives about two and one-half horse-power per square yard. How is all this energy transmitted from the sun to the earth? It is now known that there are many wave motions or vibrations transmitted through a medium called ether. These waves vary, from exceedingly short ones, so small that if they are visible it would take a powerful microscope to see them, up to a mile long. Sound waves are longitudinal while these are transverse. Sound waves are in the air or some kind of matter, while these are in ether only. When these ether vibrations are of such length that they will be detected by the eye they are called light. Light will pass through a perfect vacuum while sound will not, showing that they do not and can not travel through the same media. Light will pass through glass not as a vibration of the glass but of the ether which fills the spaces among the molecules of glass.

Until the time of Roemer, only a hundred years before the colonies signed the Declaration of Independence, the question of the speed of light was not answered. Roemer was observing the eclipse of one of the moons of Jupiter. He determined the time it took the moon to go once around Jupiter and computed the time of each eclipse for a year.

Then he observed that the eclipse fell behind his schedule and this continued for six months and then began to gain until it caught up to his computed time in six months.

We might compare this to a fact observed on Lake Michigan. At one of the lighthouses at a dangerous point there is a fog whistle which is blown by machinery once each minute. Suppose a person in a boat at this point hears the whistle blow at exactly 10 o'clock and then rows directly out from the shore two miles in a half hour. Would he hear the whistle at 10:30 o'clock? Why does he hear it about 10 seconds past 10:30? What does this

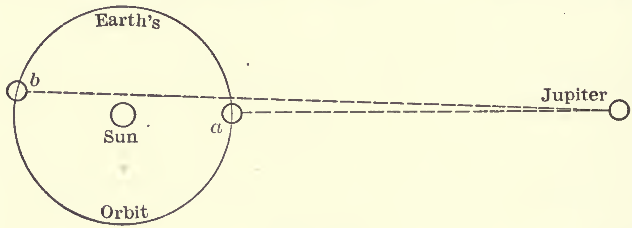


Fig. 52.

Roemer found that light from Jupiter took about seventeen minutes to travel from a to b. This is about 186,000 miles per second. The fastest railroad train would require for the same distance about 350 years if it ran without stop.

10 seconds represent? Now he rows back to shore in another half hour and hears the whistle at 11 o'clock. Why did it first lose and then gain on its schedule of blowing each minute?

In Fig. 52 the earth was at (a) when Roemer made his first computations, and when the earth was at (b), six months later, the eclipses were about 1000 seconds slow. He reasoned, therefore, that it took light 1000 seconds longer to travel from Jupiter to (b) than from Jupiter to (a) as the distance from the earth to the sun is 93,000,000 miles, the distance from (a) to (b) is 186,000,000 miles, which

gives a velocity of 186,000 miles per second for light. It is now possible to measure the velocity of light by several other methods and results agree quite closely with the above value. It is found that in such substances as glass the velocity is slower than in space.

This velocity is so great that it is difficult to realize it. Light travels a distance equal to a little more than seven times around the world at the equator in one second. If a race were to take place between a wave of light and the far-famed 20th Century Limited train, the "Limited" might have a start of one year of twelve months on a straight way without a stop, and then the ray of light could catch the train in a little less than three seconds.

When a piece of iron is placed in the forge and heated, its molecules soon become so disturbed that they start vibrations in the ether. When these vibrations are of high frequency the iron is incandescent and emits light. This process of sending out waves of ether is radiation and may be either heat or light waves. The usual source of light waves is some substance heated to incandescence. The glowworm and the firefly in some way yet unknown to man are able to emit light without heat.

When light is traveling out from any source, the wave front if undisturbed is spherical. A beam of light is the path from a point of the source to some other point and consists of a series of small elements of the successive waves. This line of travel, if the medium is alike all the way, is a straight line. If it were not, one could not sight a gun and the surveyor could not run a line with the transit.

Since light travels in straight lines, it is evident that if light be radiating from a point, and some object is placed so that it stops part of the rays, the space behind the object will be without light from the given source.

This space from which light is excluded is called a shadow.

If a screen be held up behind the object a cross section of the shadow will be obtained, which is often incorrectly called a shadow.

Fig. 53 and 54 show the difference between the shadow formed when the light is from a point and when it is from an object with a considerable size. Fig. 54 shows the position of the sun, earth, and moon, so that the moon will pass through the shadow of the earth and be eclipsed.

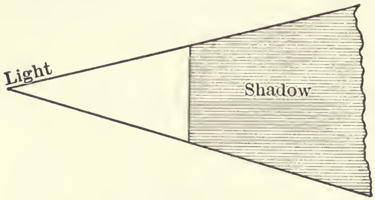


FIG. 53.

Shadow when the light is from a point.

The experience of the race has taught us to believe that under ordinary conditions light travels in straight lines.

Note. Attention should be called to the fact that this statement is only approximately true. If the student takes an advanced course in physics, he will find that because of the short wave-length of light, the statement, that light travels in straight lines in a uniform medium,

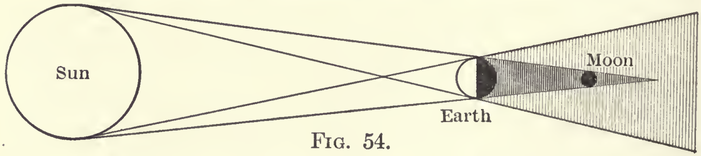


FIG. 54.

Shadow when the light is from a large surface.

is satisfactory for a high school course in physics. Let the student look through a thin fine cloth toward a bright light, or let him put a thumb mark on polished brass and look in it at the reflection of a bright light. The students who are especially interested might then be referred to Prestons' "Theory of Light."

When light radiating from a point is received by the eye, we at once assume that the object from which it comes is at that point. As a result of this, the eye is often deceived. If light from an object in front of a plane mirror strikes the mirror, it is reflected so that the *angle of incidence equals the angle of reflection.* Angle of incidence is the angle between the ray of light striking the mirror and the line perpendicular to the mirror at the point of incidence. The angle between the same perpendicular and the reflected ray is called the angle of reflection. This causes the light to appear to be diverging from a point or object as far back of the mirror as the object is in front, as in Fig. 55. This may be proved both mathematically and experimentally. The image formed in a plane mirror is a virtual image, as no rays of light actually converge at the point where the image appears to be, but only appear to do so. If a person stands before a plane mirror, the image is as far back of the mirror as the object is in front, and is virtual.

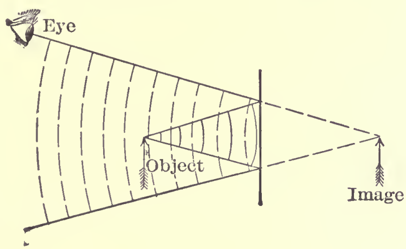


Fig. 55.

Looking in a good plane mirror the eye is deceived. An image appears to be back of the mirror as far as the object is in front.

Intensity of illumination is defined as the *quantity of light energy per unit area.* Even a child knows that to get more light on its page the book is brought nearer the source of light. This may be studied quantitatively as follows: suppose a light be placed at the center of a hollow sphere, the energy sent out is distributed over the inner surface of the sphere; if it is placed at the center of a sphere

with twice as great a diameter, the same energy is spread over the surface four times as large, since the surface of the sphere varies as the square of the diameter.

In Fig. 56, suppose a screen be held at a distance of one foot from a source of light, and a square, one inch on the edge, be cut out. If a screen be held up parallel to the first, and two feet from the source of light, the energy which was received on the square of card cut out now passes through the hole and is spread over a surface four times as large as the opening in the first card. One ounce of butter will be four times as thick spread on one slice of bread as it will be if spread over four slices of bread of the same size. We are now ready to state the law that *the*

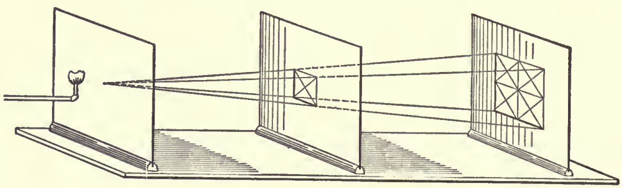


Fig. 56.

At two feet a given amount of light covers four times as much surface as at one foot.

intensity of illumination varies inversely as the square of the distance from the source of light. Ten feet from a given lamp the illumination is 1/100 as intense as it would be one foot from the same lamp. If two sources of light are to be compared, they are placed so that they shine on opposite sides of a card, and the card so adjusted that the intensity of illumination is the same on both sides. Then we may state that the intensities of two sources of light are directly proportional to the squares of the distance at which they give equal illumination. To measure the power of any light some unit must be used. The one most

commonly used is a sperm candle weighing $\frac{1}{6}$ pound and burning at the rate of 120 grains per hour. This is called one candle-power, and when we say that a light is 60 candle-power, we mean that it emits as much light as 60 standard candles. In making the measurement, a paper screen is used with a grease spot near its center. If light shines on only one side of the paper the spot will be dark on the one side and bright on the other. If the card be equally illuminated on both sides the spot will almost disappear. Sometimes two mirrors are used in order to see both sides at the same time. In measuring a certain light a standard candle is placed on one side of the screen and the light to be measured on the other. It is found that when the card is equally illuminated on both sides, the candle is 15 inches from the screen and the other light is 60 inches from the screen. Then to compute the candle-power we have, by the law of intensity,

$$\frac{1}{x} = \frac{15^2}{60^2} \text{ or } \frac{1}{16}$$

From which $x = 16$ candle-power.

The reflection of light in a plane mirror has already been discussed. Reflection of light from a rough surface follows the same law, but owing to the large number of small surfaces, the light is sent out in all directions and is called diffused light. It is by means of diffused light that we see objects.

It has been found by experiment and measurement that the velocity of light is less in glass, water, diamonds, etc., than it is in air, and that it is a little less in air than in a space free from air. Such substances are called optically dense. It is supposed that ether pervades these substances but that the molecules of the substances interfere with the speed of the ether vibrations. A substance like glass, which

will let them through, is called transparent, while a substance such as iron, which will stop them, is opaque; and one which will let part of the rays through but diffuse them so that the object cannot be seen, such as frosted glass, is translucent. If a series of wave fronts, as shown in Fig. 57, not perpendicular to the surface, enters a piece of glass, one side of a wave front (*a*) will enter the glass before the side (*c*) reaches it, and it will be retarded so

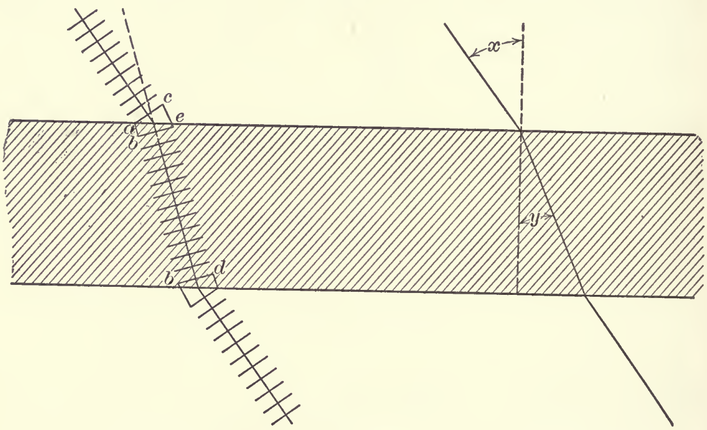


Fig. 57.

When light passes from one medium to another it is bent or refracted at the surface.

that (*c*) will run around it, and the direction of the wave will be changed and its path through the glass is a new straight line. When the wave reaches the other side of the plate and is about to emerge from the glass the side (*b*) gets out first, and on account of its greater velocity runs ahead of (*d*), so that the direction of the ray of light is changed again and takes another straight line. If the two surfaces of the glass are parallel, the change in velocity and therefore the change in direction of the ray of

light is the same at each side and the emergent ray is parallel to the entrant ray. The angle x between the ray and the perpendicular is the angle of incidence, the angle y between the ray and the perpendicular is the angle of refraction. The change in direction of light rays at the surface of a substance is refraction.

This refraction leads to many familiar deceptions of the eye. A stick thrust into clear water appears bent at the surface. Objects under water seem to be lifted toward the surface. When in bathing, your feet seem to be nearer to you than they are. The bottom of the lake seems to run out level, but when you wade out it becomes deeper.

The veolcity of a light is always the same in a given substance and the refraction of light depends upon the velocity, that also may be measured. When light passes from a vacuum into a substance, an examination of Fig. 57 will show that the angle of incidence is greater than the angle of refraction; (x is greater than y) when light passes from a vacuum into a substance. The sine of the angle of incidence divided by the sine of the angle of refraction is the **absolute index of refraction.** When light passes from one medium to another, the sine of the angle of incidence divided by the sine of the angle of refraction is the relative index of refraction. This is usually written

$$\frac{\sin i}{\sin r} = u$$

In general, when light passes from a rarer to a denser medium, it is bent toward the perpendicular. When it passes from a denser to a rarer medium it is bent from the perpendicular.

The index of refraction for a few substances is as follows: Water 1.33, Crown glass 1.52, Flint glass about 1.62, Diamond 2.47.

In Fig. 58 a ray of light is incident at (*o*), coming from a dense medium to a rarer. In that case (*r*) is larger than (*i*) and as the incident ray swings toward (a^1) the refracted ray will move toward the surface and (*r*) becomes 90°. If the incident ray *x* moves farther toward the surface, as at (a^1), the refracted ray cannot follow the law of refraction any farther and is then *all* reflected from the surface as from the plane mirror and is said to be totally reflected. The angle of incidence, when the angle of refraction is 90°, is the critical angle. When the critical angle is passed the ray is totally reflected; such a reflecting surface is the best reflector known. The sparkle and glow of the diamond is largely due to the fact that its index of refraction is large, and therefore light soon passes the critical angle and is totally reflected.

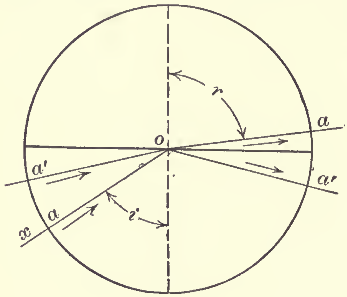


FIG. 58.

If white light be passed through a glass prism, as in Fig. 59, it is twice refracted in the same direction, and, besides its deviation from the original direction, it is found to be dispersed, that is, separated into different colors. These colors correspond to light of different wave-lengths, much as pitch in sound depend upon different wave-lengths. The red, which is least refracted, is the longest, about .000081 cm.; the violet, which is the most refracted, is the shortest

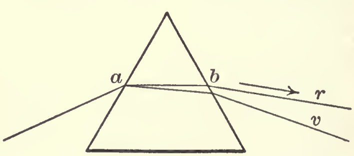


FIG. 59.

White light passed through a prism is twice refracted in the same direction and is separated (dispersed) into the colors of the rainbow.

or .000033 cm. It is customary to speak of seven colors in the solar spectrum — red, orange, yellow, green, blue, indigo, violet. It is now known that these seven may be made by properly combining red, green, and violet. The primary colors then are red, green, and violet. Between the extremes there are thousands of wave-lengths which cause these colors to shade into each other in an endless number of shades. The color of light then depends upon its wave-length, while the color of a body depends upon the color of light it reflects. If a body reflects only red and absorbs all other colors it is red. A piece of glass so colored that it will only transmit blue light is blue. Some artificial lights are lacking in one or more colors. When this is the case, objects will not appear to be their correct colors under these lights. For instance, the mercury vapor arc has no red in its light. If you will go to the engine room in the evening and stand under the mercury vapor arc you will see a peculiar change. The lips are red and hence reflect only red light; there is no red in this light and hence the lips reflect no light at all and appear black.

In Fig. 59 the ray of light is twice bent toward the base or thicker side of the prism. If two such prisms are placed base to base and then ground until each face is part of the surface of a sphere, a double convex lens would be produced, and rays striking the surface would be twice bent toward the center and brought to a point. If parallel rays strike the lens, as in Fig. 60, the point F, at which they focus, is the

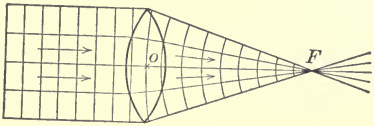


FIG. 60.

Parallel rays of light brought to a point (focus) F, by means of a convex lens. The burning glass is an example.

principal focus; O is the optical center; OF is the axis and OF is the focal length (f.)

In the back of the eye there is a layer of rods and cones each forming an end of a fiber of the optic nerve. It is supposed that these are of three kinds, one set responding to red light, one to green and one to violet light. If all are stimulated at once the effect is that of white light. If a proper mixture of the red ones and the violet ones is stimulated, the sensation given to the brain is that of a yellow light. The most common form of color-blindness is called red-blind. It is probably because the red rods and cones are either defective or inactive. They cannot distinguish red from the other colors.

A beautiful effect produced by separating white light into its colors is seen in the rainbow, when the sun is shining low in the heavens on one side and rain is falling on the opposite side; the light entering the drops of water is reflected to the eye from the back side of the sphere, and is refracted at the surface so that the colors are separated. Standing at the brink of Niagara one may often see the complete circle in the mist.

When light is twice refracted in the same direction through a prism or a lens, the light is bent from a straight line and also separated into colors. A convex lens will focus the light from an object, but the colors will focus at different points and the image will not be sharp. When the red is in the focus every object will be surrounded by a band of rainbow colors. This is called chromatic aberration and would be undesirable in a camera. Photographs of most of our neighbors would not look natural if each had his head surrounded by a halo. It is found that crown

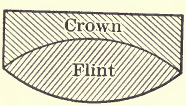


FIG. 61.

Lens made of two kinds of glass, to focus all colors alike.

and flint glass, having the same dispersive power, do not have the same refractive power. A lens built up of two kinds of glass in the proper proportions will focus all colors alike and is called achromatic (without color). A section of such a lens is shown in Fig. 61.

APPLICATION OF LENSES TO OPTICAL INSTRUMENTS

The eye (Fig. 62) is a small camera. A ball about one inch in diameter has an opening in front at which the crys-

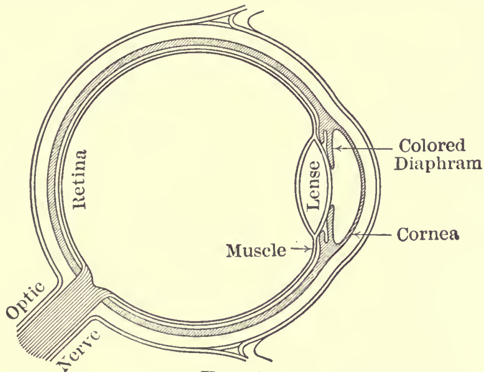


Fig. 62.
Section of the human eye.

talline lens is placed, and a sensitive coat composed of nerve endings at the back, upon which the real image is formed. An object in front of the eye reflects light, which enters through the pupil of the eye and is focused in a real, inverted image on the retina by the crystalline lens. The distance from the front to the back of the eye cannot be changed, so when objects are at different distances the accommodation is made by changing the curvature of the lens by means of the muscle surrounding it. When the eyeball becomes too long, so that the image is formed before reaching the retina, only near objects can be seen dis-

tinctly, and distant objects are blurred. Such an eye is near-sighted (myopic). The defect is corrected by concave glasses.

In the laboratory five possible positions were found for the convex lens.

1. When the object is beyond 2*f*, the image is real, inverted, smaller. This is the position used in the camera for taking all ordinary pictures. See Fig. 63.

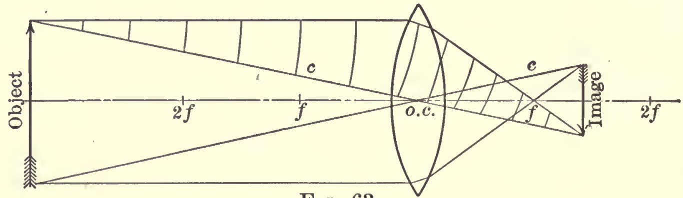


FIG. 63.

2. When the object is between *f* and 2*f* the image is beyond 2*f*, real, inverted, and larger than the object. This is the position used in the projection lantern. The slide is placed in the lantern at a distance a little greater than 1*f*, the image being formed on the screen enlarged and inverted, as in Fig. 64.

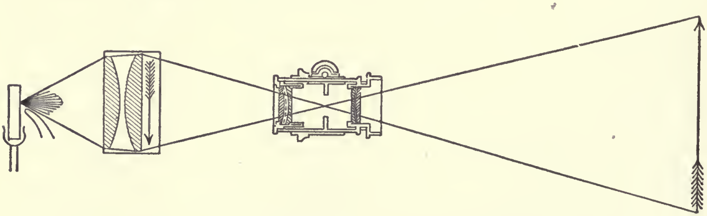


FIG. 64. — Projection lantern or moving-picture machine.

In front of a powerful light a lens, as in setting 4, throws almost parallel rays through the slide or film. A convex lens in position 2 is then used to form a large image upon the screen. If sixteen or more per second are thrown on the screen the impression of one upon the eye lasts until the next is presented and the result appears to be a continuous moving picture.

3. When the object is at $2f$ the image is at $2f$, inverted and real. This is the position used in taking a life-sized picture with the camera.

4. When the object is at f, the rays diverging from it upon the lens leave the lens in a parallel beam of light. This is used in the dark lantern to throw a strong beam of

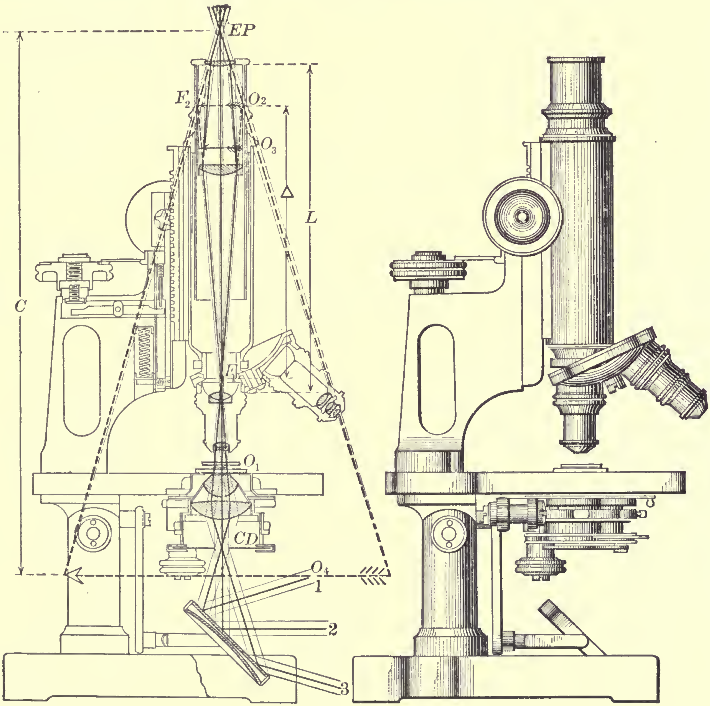


Fig. 65. — Compound Microscope.

A mirror reflects light upward through the semi-transparent object O_1. A convex lens converges the rays of light toward O_2, but another convex lens in the eyepiece converges them to a real image O_3. A convex lens is used as a simple microscope to cause the rays of light coming from this image to appear to come from the large virtual image O_4.

light to a considerable distance by placing the light at *f*. The same setting is used in the condensing lens of the projection lantern to throw a strong light upon the slide.

5. When the object is between *f* and the lens no real image is formed, but by looking through the lens a virtual, enlarged image is seen. This is used in the simple microscope and in the reading glass, or the eyepiece in a telescope, as lens *b*, Fig. 66.

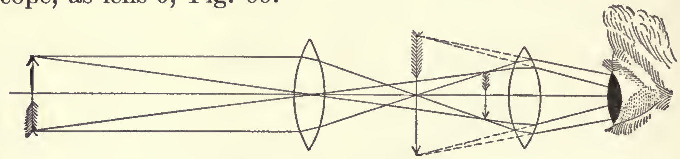


Fig. 66. — Telescope.

The telescope uses a convex lens for the object glass and forms a real inverted image, just as the camera does. This is sometimes reinverted by a second convex lens and then seen through a simple microscope.

The compound microscope is composed of two parts: a convex lens, set as in a projection lantern, forms an enlarged real image in the barrel of the microscope. The eyepiece is a simple microscope used to enlarge this image again.

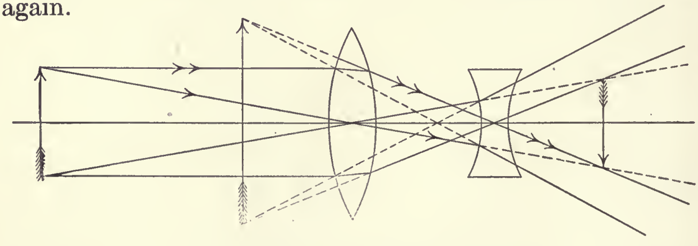


Fig. 67. — Opera Glass.

In the opera glass a convex lens deflects the rays of light toward an image (b). A concave lens is interposed so that the rays do not focus but appear to the eye to come from point (b'). The result is to bring the object apparently near without inverting it.

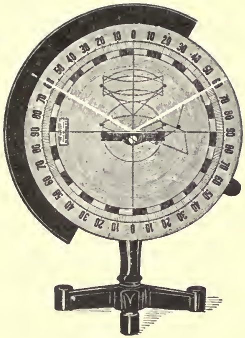
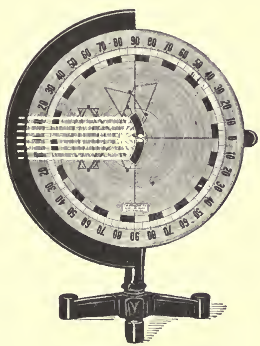


FIG. 68. FIG. 69.

Optical disk, showing reflection of light in mirrors.

When light is reflected by a plane mirror the angle of incidence is equal to the angle of reflection and right and left are reversed. (Figs. 68 and 69.)



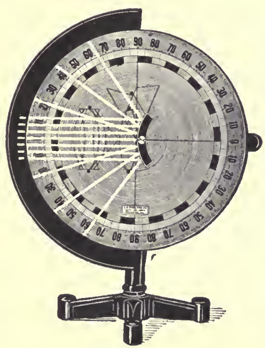


FIG 70. FIG. 71.

Optical disk, showing reflection of light in mirrors.

The concave mirror focuses parallel rays at a point called the principle focus (Fig. 70). The convex mirror tends to diverge light reflected from its surface (Fig. 71).

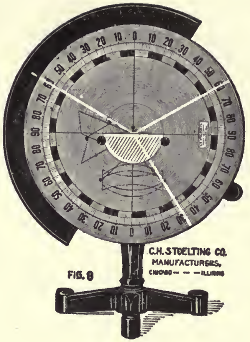


FIG. 72. FIG. 73.

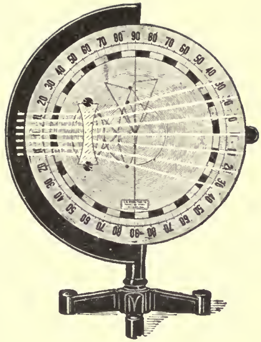
Optical disk, showing effect of refraction of light.

Light passing from air to glass is partly reflected and partly refracted toward the perpendicular (Fig. 72). Light passing from glass to air is bent from the perpendicular (Fig. 73).

FIG. 74. FIG. 75.

Optical disk, showing effect of refraction of light.

Rays of light parallel to the principle axis of a convex lens meet at the principle focus (Fig. 74). Rays of light diverging from a distance equal to the focal length upon a convex lens, leave as parallel rays (Fig. 75).



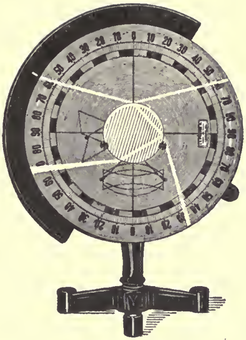


Fig. 76. Fig. 77.

Optical disk, showing reflection and refraction of light.

The concave lens tends to diverge light passing through it (Fig. 76). Fig. 77 shows how light passes through the drop of rain when a rainbow is formed.

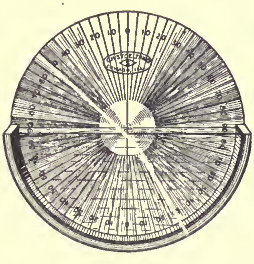


Fig. 78. Fig. 79.

Optical disk, showing reflection and refraction of light.

The total reflection or right angle prism is often used in optical instruments. The light strikes at greater than the critical angle (Fig. 78).

A semi-circular tank of glass may be used to show the refraction of light at the surface of a liquid.

8

CHAPTER VII

HEAT

All scientists agree that heat is a form of energy. It is supposed to be motion of the molecules composing matter. The molecules according to the general accepted theory are not in a state of rest but are moving and vibrating back and forth, some slowly, some rapidly. If the motion is slow the body feels cold, if the motion is rapid the body feels warm. Due to its inertia any body in motion possesses energy, hence it is considered that heat is a form of kinetic energy. Heat may be readily transformed into vibration of ether, like light vibrations, except that the waves are longer, when it behaves, in most respects, exactly as light waves do. It is in this form that heat travels from the sun to the earth. Radiant heat may be changed back to molecular vibrations when it becomes kinetic energy.

The term temperature is used to indicate that a body is hot or cold. It indicates whether the molecules of the body have a high speed or a low speed. A hot body has a high temperature while a cold body has a low temperature. When a body receives heat from any source, its temperature rises; when it loses heat its temperature falls. It is a common mistake to suppose that temperature is a measure of the quantity of heat a body possesses.

A teapot full of water may have the same temperature as the water in Lake Erie, yet the quantity of heat in Lake Erie is much greater than the quantity of heat in the tea-

pot full of water. If the teapot is heated to the boiling temperature, its quantity of heat is increased, but the total quantity of heat energy it possesses is much less than the quantity of heat energy possessed by the lake at a lower temperature.

The method of measuring temperature and of measuring the quantity of heat present in a body are very different. For measuring temperature the thermometer is generally used. A long, thin, glass tube with a bulb at one end is partly filled with mercury. The space above the mercury must contain no air. If the mercury is heated it expands in proportion to the change in temperature. In the Fahrenheit scale, the one generally used in this country, the point where the mercury stands when the bulb is surrounded by melting ice is marked 32°. The point where the mercury stands when placed in steam over boiling water under the pressure of air at sea-level is marked 212°. The space between them is then divided into 180 equal parts. The centigrade scale has the same two fixed points marked 0° and 100° respectively and the space between divided into 100 equal spaces. If these two scales be placed side by side, as in Fig. 80, it is evident that 0° C. is the same as 32° F. and that 100° C. is the same as 212° F., also that 180° F. covers the same space as 100° C. Therefore 1° F. is the

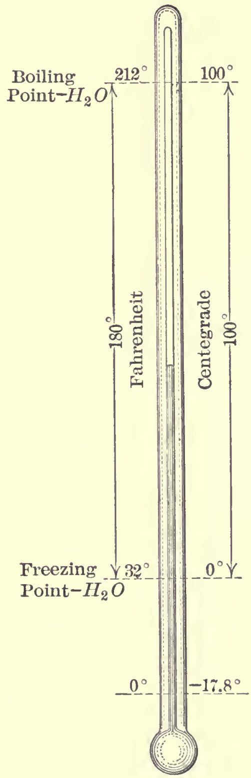


Fig. 80.

same as $\frac{5}{9}$° C. To change 20° C. to Fahrenheit, $20 \times \frac{9}{5} =$ 36° F. above the freezing point. $36° + 32° = 78°$ F. All changes must be computed above the freezing point. To change 104° F. to C., $104° - 32° = 72°$ F. above freezing point. $72 \times \frac{5}{9} = 40°$ C.

Heat cannot be measured in pounds or quarts as substances are, but must be measured by the effect it produces. It is found that the quantity of heat required to raise the temperature of one unit of water one degree is almost the same at any point between the freezing and boiling points, that is, it takes almost the same quantity of heat to raise the temperature of one gram of water from 2° C. to 3° C. that is required to raise the temperature from 75° to 76° C. Therefore the quantity of heat required to raise one gram of water 1° C. is taken as the metric unit of heat and is called the calory. This unit is very small. When a large quantity of heat is to be measured a larger unit, known as a great calory or kilogram calory, is used. This is the quantity of heat required to raise the temperature of one kilogram of water 1° C. It is equal to 1000 gram calories and is approximately equal to 4 B.T.U.'s. In the English system the quantity of heat required to raise the temperature of one pound of water 1° F. is taken as the unit and is called one British Thermal Unit. (B.T.U.)

Suppose we take a vessel partly filled with water at the freezing temperature. If the vessel be placed on the stove, and heat applied, the millions of molecules at first moving slowly will begin to move faster as the heat is transferred to them. Their kinetic energy increases and the temperature rises. After reaching a certain temperature the molecules, in addition to their rapid movement, also move farther apart and their paths are longer between bumps. As the molecules move farther apart, the space

occupied by the water becomes larger and the body expands.

If we take a block of ice at a temperature of $-10°$ C. and apply heat while a thermometer is in contact with it, we will find that the temperature rises until the thermometer stands at 0° C. and will then become stationary. As soon as this temperature is reached, the ice begins to melt and the heat applied instead of raising the temperature is all used up to produce the change of state from solid to liquid. The temperature of the liquid will remain at 0° until the ice is all melted. If more heat is now applied to the water its temperature will gradually rise, until, if it is in an open vessel at sea level, its temperature reaches 100° C. No matter how much heat is applied to the water the reading of the thermometer will remain stationary at 100° C. and cannot be made to rise higher. The molecules have been set into such rapid motion that the attractive forces can no longer hold them and they tend to separate. The liquid changes to a gas, that is, steam, and the heat is being used to produce this change.

The heat that is used in changing a solid to a liquid or a liquid to a gas is called latent heat. The portion of heat that produces change in temperature may be detected by the sense of feeling and is therefore called sensible heat. Changes in volume have also been taking place in the water. While the ice is being heated from $-10°$ to 0° the ice expands slowly. At the point of melting, the water at 0° occupies about $\frac{5}{6}$ the volume of the ice at 0°. The water contracts until it reaches 4° C., after which it expands almost uniformly until it reaches 100°. Nearly all substances expand as heat is applied to them.

We have noted the following effects produced by heat:

1. It increases the rate of motion of the molecules as indicated by the rise of temperature.

2. It increases the length of the paths and the distance between the molecules, causing the body to expand and occupy more space.

3. It overcomes the force of cohesion, changes the state of a matter from a solid to a liquid and from a liquid to a gas.

The heat used in changing a solid to a liquid is called the latent heat of fusion. It has been found by experiment that to change one gram of ice at 0° C. to water at the same temperature, requires 80 calories. Hence we say that latent heat of fusion of ice is 80. Expressed in the English system the latent heat is 144 B.T.U., which means that 144 B.T.U. are required to change one pound of ice to water without changing its temperature.

The latent heat of steam is the heat required to change water to steam without changing its temperature. In the metric system this is 537, that is, to change one gram of water to steam at atmospheric pressure requires 537 calories. To change one pound of water to steam at 212° F. takes 966 B.T.U.; in other words, to change one pound of boiling water to steam at 212° F. requires 966 times as much heat as is needed to heat one pound of water from 62° to 63° F.

You perhaps have never considered the process of freezing as a heat producing process, but it is. When one pound of Lake Erie water freezes, the 144 B.T.U. it contained as latent heat are given out to the air and help to keep the temperature of Cleveland mild in winter. This same pound of ice placed in your refrigerator must take in 144 B.T.U. in order to melt, and takes it from the surrounding substances and cools the meat and butter. The same ice may be packed around a can containing cream. Salt mixed with the ice will cause it to melt and it must have its latent heat from somewhere; so it takes it from the cream and you have ice cream for dinner.

The calory has been defined as the quantity of heat required to warm 1 gram of water 1° C. If we warm one gram of brass 1° C., it will not require as much heat. Suppose we take two vessels exactly alike, each containing the same amount of water at 20° C., and in one of them place a brass ball weighing 526.3 grams and at a temperature of 100° C.; we find that it warms the water to 60° C. If then we pour boiling water at 100° C. into the other, taking care to add only enough to warm the water to the same temperature, 60°, we will then find that we have added only 50 grams of water. As each vessel was alike and contained the same amount of water and was warmed from 20° to 60°, each must have received the same amount of heat. The brass and the hot water are each cooled the same amount, from 100° to 60°. It took 526.3 grams of brass to furnish the same amount of heat as given out by 50 grams of water, .095 as much water as brass. Hence the same weight of brass gives out only .095 as much heat as water when cooled through the same number of degrees. The specific heat of a body is the ratio between the amount of heat required to warm the body through 1° and the heat required to warm an equal weight of water 1°. When we say that the specific heat of iron is .1138 we mean that to warm any weight of iron 1° requires only .1138 as much heat as would be required to warm the same weight of water 1°. The amount of heat to warm 1 gram of water 1° C. is one calory and .1138 of that would be .1138 of a calory, hence the specific heat of a substance is often defined as the number of calories required to heat one gram of a substance 1° C. Both definitions are the same. The specific heat of a few substances is given below:

Aluminum	.22
Brass	.094
Copper	.095

Iron	.1138
Mercury	.038
Lead	.031
Ice	.5
Air (at constant pressure)	.2375
Hydrogen (at constant pressure)	3.4
Steam (at constant pressure)	.48

What difference would it make in the rate of warming up in the spring and cooling in the fall if Lake Erie were iron instead of water? Which is the best foot-warmer for a long cold ride — soap stone, hot water bottle, or a flat iron? Why?

When heat is applied to a metal, one of the effects is to cause molecules to vibrate faster and increase the length of their paths crowding the other molecules back and making the total space occupied by the body larger. The rate of expansion is not the same for different metals. *The fraction of its length which a body expands while its temperature is raised 1°, or the expansion of unit length for one degree change in temperature is the coefficient of linear expansion.*

The following coefficients are given per degree Centigrade. Since the Fahrenheit degree is $\frac{5}{9}$ of the Centigrade degree these may be changed to the Fahrenheit by multiplying by $\frac{5}{9}$.

Aluminum	.0000222
Brass	.0000187
Glass	.0000083
Iron	.0000112
Platinum	.0000088
Steel	.0000013 (tempered)
Steel	.0000011 (untempered)

The Hippodrome has put in a steam pipe 400 feet long, and to allow for expansion "expansion collars" are put in. Each of these allows the end of the next pipe to slip within it, giving $1\frac{1}{2}$ inches free play. How many of these must

be put in to allow for a range in temperature from 32° F. to 232° F?

Examine the *balance wheel of a watch*, the *pendulum* of a clock, and the thermostat, to see how the different rates of expansion for two metals are applied.

Why should the pattern to be used in the foundry be made larger than the finished casting is to be? The melting point for brass is 1020° C. and for iron from 1500° C. to 1600° C. Figure out a general rule to give to the pattern maker, who may be working in your shop some day, regarding the allowance to be made for shrinking in casting each of the above metals.

Why do castings often "warp" in cooling? Why is platinum the only metal which can be successfully sealed in glass?

If a bar of iron is heated it will expand in width and thickness as well as in length. As these expansions are all small the corners are neglected and the coefficient of the cubical expansion is taken as three times the linear expansion.

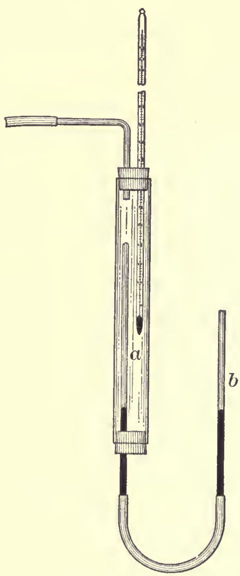


FIG. 81.

If a gas is confined in a cylinder with a movable piston fitted so that it moves easily but yet is air tight, any expansion of the gas will force the piston back against the pressure of the air and we will have the gas expanding under constant pressure. We will find that the expansion of all gases follows the same law and that each expands $\frac{1}{273}$ of its volume at 0° C., if the pressure remains constant, or that the pressure changes $\frac{1}{273}$ of

its pressure at 0° C. if the volume is kept constant. If a gas is cooled while the pressure is constant, it will contract $\frac{1}{273}$ of its volume at 0° C. for every degree change in temperature. If it were to keep this up while it was cooled from 0° C. to –273° C. its volume would decrease to 0. For this reason –273° is taken as absolute 0. The law then may be stated that *at constant pressure the volume of a gas is proportional to its absolute temperature, or at constant volume the pressure of a gas is proportional to its absolute temperature.* This is known as the Law of Charles and holds for all gases except when they are near their point of liquefaction.

Fig. 81 shows a simple form of apparatus for demonstrating the Law of Charles. Tube *a* contains dry air, and by adjusting *b* so that the mercury is at the same level in *a* and *b* the confined gas is at a pressure of one atmosphere. By filling the jacket first with ice, then with cold water, hot water, and last with steam, the volume or length of *a*, which is proportional to volume, may be taken at temperatures from 0° to 100° C. The results plotted as Fig. 82 give a line crossing zero volume at a point very near –273 C.

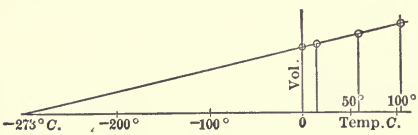


Fig. 82.

Problems

1. How many $1\frac{1}{2}$-inch expansion collars must be put into a 700-foot steam pipe to allow for a range of temperature of 200° F.?

2. The pattern maker allows $\frac{1}{8}$ inch per foot for shrinkage in making a pattern for cast-iron if the melting point of iron is 2075° F. how much of this is for contraction and how much for machining?

3. If the melting temperature of brass is 1692° F. how much must be allowed for shrinkage in making patterns for brass casting? How much for aluminum castings, melting temperature being 1157° F.

4. Why is platinum always used where a metal must be sealed into glass to make an air-tight joint?

5. How much steam will be required at 212° F to melt a ton of ice at 32° F.?

If one pound of coal yields 11,000 B. T. U., and one half is lost in radiation, how many pounds will be required to melt 100 pounds of ice at 32° F. and change it to steam at 212° F.?

6. If 1000 pounds of water enter the boiler of a locomotive and leave the engine as exhaust steam, how many B.T.U's do they carry away as latent heat?

CHAPTER VIII

ENGINES

We have noted that heat is a form of kinetic energy. Every boy has observed that, when a hammer strikes a piece of iron, mechanical energy is changed to heat. Electrical energy is changed to heat in the electric lamp, and stored chemical energy is changed to heat in the firebox when coal or any fuel is burned. The question arises, can the process be reversed — can heat energy be changed into mechanical energy for doing useful work? For answer, ask yourself what runs the steam-engine, the gas-engine, or the hot-air engine.

THE STEAM-ENGINE

When a vessel of cold water is placed over a fire the water at the bottom in contact with the heated portion of metal is warmed. This causes the water to expand and therefore becomes lighter. It is then pushed up by the heavier cold water which flows in to take its place. This circulation, known as convection currents, is kept up until the whole mass of water is heated. We have already learned that heat makes the molecules of water move about or bound to and fro faster. Some of them will move so fast that they will jump through the surface into the air. This is evaporation and takes place more rapidly as the temperature rises. The pressure of the air normally is 14.7 pounds. When the particles of water get to moving so rapidly that their pressure trying to jump out is equal to the pressure of air on the surface, they will escape rapidly and force the

air back. The temperature at which they do this is the boiling point. It is evident that as the pressure is increased the speed with which the molecules move before they will jump out must be greater, that is the temperature must be higher. *The boiling point of a liquid is the temperature at which its vapor tension is equal to the applied pressure.* The boiling point of water at normal pressure is 212° F. The boiling point in the boiler of a Lake Shore locomotive running at 200 pounds is about 387 F. While at a height of three and one-half miles above sea level, where the pressure of the the air is $7\frac{1}{2}$ pounds per square inch, the boiling point is only 180° F.

One cubic foot of water weighs $62\frac{1}{2}$ pounds, but one pound of water changed to steam at the pressure of the atmosphere occupies 26.4 cubic ft., that is, the $62\frac{1}{2}$ pounds would occupy 1650 cubic ft., at a pressure of 14.7 pounds per square inch. If water in a closed boiler is heated the space will soon be filled with steam and the pressure will rise. The pressure rises until a balance occurs, then the particles of steam condensing to water are equal to the particles of water jumping off. The space contains all the steam it will hold at the given temperature. Any increase of pressure will cause some of it to condense and any decrease in temperature will cause some of the steam to condense. This is called saturated steam. Boiler steam in contact with water is always saturated steam. If the same steam is conducted to a chamber separated from the water and heated above the boiling point corresponding to its pressure, it is called superheated steam.

We are now ready to study the steam-engine. Examine the engine in the laboratory and draw a section of the working parts. Compare with Fig. 83.

Live steam from the boiler is admitted to the steam chest through pipe *a*. In the position shown the steam

passes through port *b* to the left or head end of the piston and pushes it along. The exhaust steam in the right or crank end of the cylinder is driven out through the port *e*

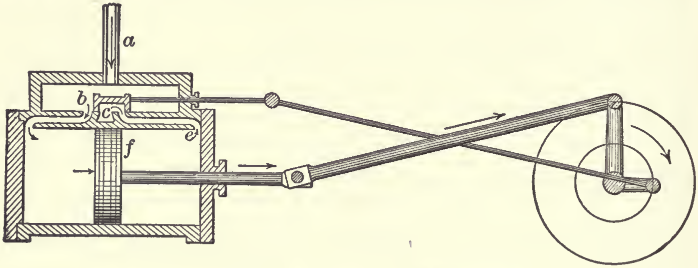


FIG. 83. — Slide valve steam-engine.

to the exhaust pipe *c*. As the stroke progresses the valve is moved by the eccentric so that it closes the port *b*, not admitting any more steam to the left end of the cylinder.

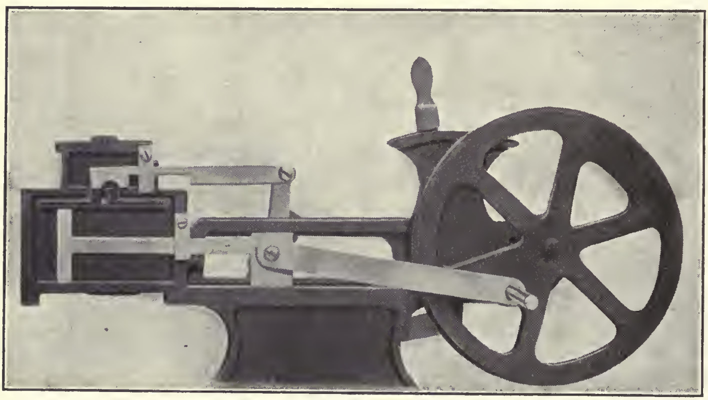


FIG. 84. — Section model of a slide valve steam-engine.

The continued motion of the valve then releases the steam in the head end of the cylinder to the exhaust, and admission at the other end takes place and live steam rushes in to

push the piston back. Opening the port for live steam is called "admission"; closing the live steam port is "cut off." Opening the exhaust port is "release"; closing the exhaust port is "exhaust closure." The valves are usually set so that the admission takes place a fraction of a second before the piston reaches the end of its stroke in order that the space may be filled with live steam when the return stroke begins: this is called "lead."

The horse-power of a steam-engine is rated by two methods. One is called the delivered or brake horse-power and is measured by the Prony brake as already described. This measures the actual delivered horse-power. The other method is by means of the indicator card. If the pressure on the piston were the same as boiler pressure throughout the length of the stroke, the horse-power would evidently be the total pressure tending to move the piston multiplied by the distance the piston moves per minute, divided by 33,000. The total pressure tending to move the piston is the difference between the pressure per square inch on the live side and the back pressure per square inch on the exhaust side multiplied by the piston area in square inches. In practice however it is not advisable to admit live steam from the boiler throughout the stroke. It is far more economical to admit steam at boiler pressure for part of the stroke (from one third to one-half of the length of the stroke) and then have the valve "cut off," that is, close the entry port. The inclosed steam then continues to push the piston along for the rest of the stroke, expanding as it does so. During this part of the stroke no more energy is added to the steam cylinder. The steam is expanding and doing work at the expense of its own temperature. Energy which would be carried away as heat is saved for useful work. It is advisable to have the steam enter the cylinder as hot as possible and leave it as cool as

possible. The compound engine allows this expansion and consequent drop in temperature to take place twice or even four times in the quadruple expansion engine. While this expansion is taking place the pressure drops and the average pressure during the stroke must be used in computing the horse-power.

The indicator is a device for finding this mean effective pressure and at the same time showing the setting of the valves of the engine.

Fig. 85 shows part of the mechanism of the indicator. A tap is made in each end of the cylinder. This tap at one end of the cylinder is then connected to pipe at the bottom of the indicator. The steam forces the piston (b) whose area is $\frac{1}{2}$ inch up against a spring and in doing so carries pencil (d) up a distance proportional to the amount of pressure. If, while the cylinder (e) stands still steam is alternately admitted and withdrawn from the indicator, the pencil traces the straight vertical line. The cylinder (e) is carried on a pivot and connected with a string to the piston rod of the engine, so that it revolves back and forth as the piston rod makes its stroke. If no steam is admitted to the indicator while the cylinder revolves, the pencil will trace the horizontal line (y). If both these take place at the same time while the engine is working, the pencil will trace a curve representing the two variables, the one on the vertical or

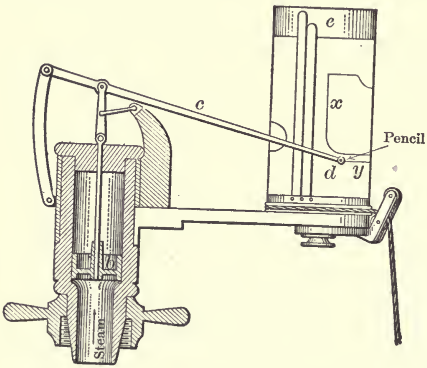


Fig. 85. — Steam indicator.

(x) axis being proportional to the pressure pushing the piston, and the one on the horizontal axis being proportional to the movement of the piston on its stroke or in proportion to the volume behind the piston.

Such a card for the head end of a Corliss engine is shown in Fig. 86. A is point of admission taking place just as the piston is at the end of its stroke and the line rises along the vertical line to B. BC is the steam line, steam at boiler pressure being admitted. C is the point of "cut off." From C to D the steam is working expansively. CD is the expansion line, and during this time pressure and temperature are falling. D is the release, EF is the back pressure line during exhaust, F is exhaust closure. This takes place before the piston reaches the end of its stroke in order to confine enough of the exhaust steam to cushion the reciprocating parts of the engine which may weigh several hundred pounds and would soon pound the engine to pieces if their rapid motion were not stopped against this elastic cushion of steam. The line FA is the compression line showing the rise of pressure as the parts are cushioned.

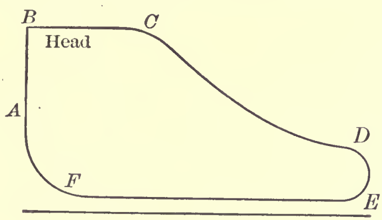


Fig. 86.

To find the horse-power: The springs commonly used for the indicator are so made that the figure is drawn to scale 1 inch to 80 pounds or 1 to 100 or 1 to 120, etc. If the average altitude of the figure between the steam and expansion line for one side of the stroke and the back pressure line on the other side of the stroke is used and multiplied by the scale of the spring, the result is the mean effective pressure. Then we have $H = \frac{PLAN}{33,000}$

Where H = Horse-power
L = Length of stroke in feet
P = Mean effective pressure
A = Area of piston in square inches
N = Number of times steam pressure is applied to the piston per minute or in the steam-engine twice the R.P.M. The result is called the indicated horse-power and is always somewhat larger than the brake horse-power.

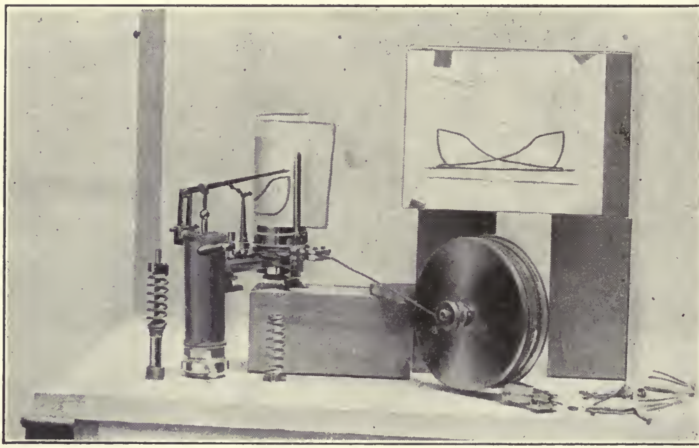


Fig. 87.
Steam indicator, piston, extra springs, reducing wheel, and a card or diagram taken on a 400-horse-power Corliss engine.

The efficiency of the best reciprocating engines is a little below 15% and of the best locomotive about 10%. That is, of all the stored energy in the form of fuel put in, only about 10% is delivered as useful work. About 70% is lost in the form of heat losses which cannot be recovered.

In an indicator card the average height is .812 inches; spring 40 was used; 100 R.P.M.; stroke 30 inches; piston diameter 15 inches. What is the indicated horse-power?

$2 \times 40 = 80$ scale of spring used

$80 \times .812 = 64.96$ lbs. Mean effective pressure

$100 \times 2 = 200$ times steam is admitted

$30 \div 12 = 2\frac{1}{2}$ ft. stroke

$(15)^2 \times .7854 = 176.7$ square inches area of piston

$$\text{H.P.} = \frac{PLAN}{33{,}000} = \frac{64.96 \times 2\frac{1}{2} \times 176.7 \times 200}{33{,}000} = 175.9 \text{ H.P.}$$

In an indicator card the average height is .642 inch; spring 30; 200 r.p.m.; piston diameter 9 inches; stroke 15 inches. What is the indicated horse-power?

1. Divide Fig. 49 into ten spaces, measure the altitude of each, and get the average height. If it was taken with spring 30 and the engine was running 150 R.P.M., diameter of piston 10 inches, length of stroke 30 inches, what is the indicated horse-power?

2. Average height of indicator card is .45 inch, spring 60 was used, diameter of piston 18 inches, stroke 30 inches, 300 R.P.M. What is the horse-power?

STEAM TURBINES

There are at present on the market three types of turbine engines, DeLaval, Westinghouse-Parsons, and the Curtis turbine. As the Curtis turbine in a measure combines the other two we will describe that one only. In the Curtis turbine the parts shown in Fig. 88 are arranged in the circumference of a circle. The moving blades (*b.b.*) are carried on the circumference of a wheel. An observer at the center looking out would have the view shown here. The steam expanding through nozzles at *a.a.* comes with great velocity to the moving blades *b*. These are driven forward, not by steam pressure but by the kinetic energy of its impact. The second row of blades (*c*) is held stationary to change the direction of the steam so that it will strike the next row of moving blades the same as it did the first. The steam is carried through a large number of

these rows of blades. As the steam expands, the circumference of successive rows is increased by placing them on

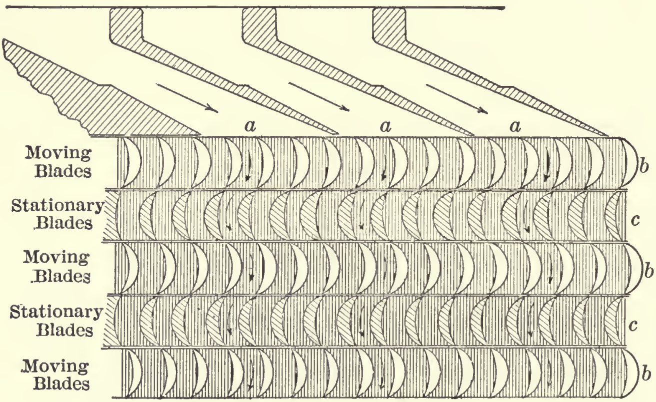


Fig. 88.

circles of larger diameter. The turbine is not reversible and works at its best efficiency when running at high speed for a long continued run. They occupy much less space than reciprocating engines of the same horse-power. These facts combine to make them valuable for ocean steamship service.

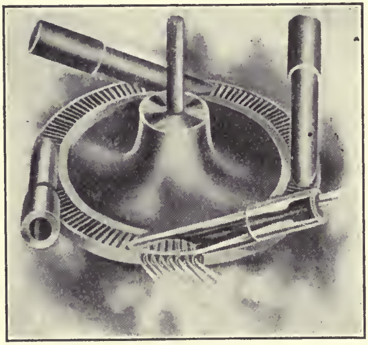


Fig. 89. — De Laval turbine, with a single set of blades.

The turbine works at its best efficiency when the steam is expanded and moving at high speed. On the other hand the reciprocating engine works at its highest efficiency when the steam is at high pressure. The

efficiency of the best reciprocating compound engines is almost 14% and that of the best turbines about 15%.

The Subway power plant of New York has recently installed turbines between the condensing chamber and the low-pressure cylinder of the compound reciprocating engines and found the combined efficiency 22.3%. They have almost doubled the power output of their plant without increasing the floor space or the amount of coal used. This is the greatest advance in steam engineering in recent years.

The horse-power of a turbine cannot be taken by indicator card, hence the rated horse-power is the brake or delivered horse-power.

THE GAS-ENGINE

The gas-engine is a heat engine. In the "four-cycle" engine shown in Fig. 90, the piston on its down stroke draws in a mixture of explosive gas, either gas, gasoline vapor, alcohol vapor, or coal oil vapor, mixed with the proper proportion of air. On the return this gas is compressed, and then the spark at the spark plug (*a*) explodes the mixture. The heat generated causes the gases to expand and push the piston down. On the next return stroke the exhaust valve is mechanically opened and the gases are driven out ready for the next cycle. It will be seen that there are two revolutions or four strokes to each explosion. In the two-cycle engine there is an explosion for each revolution or two strokes.

Fig .91 is a section of a three-port valveless two-cycle engine. When the piston is near the top of its stroke the explosive mixture is drawn in at *a*, passing to the air-tight crank case. This is somewhat compressed on the down stroke. The exhaust port is at *c*, and opens slightly before the port *d* is uncovered. When the piston is at

the lower end of its stroke the burned out gases pass out at *c* and the mixture from the crank case passes in at *d*. A baffle plate or deflector prevents its blowing across and

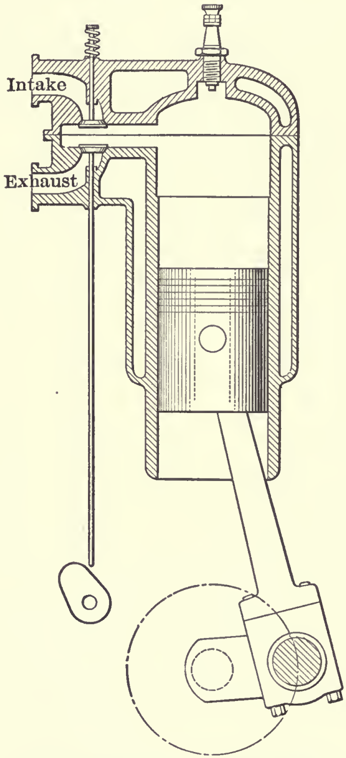


Fig. 90. — Four-cycle gas-engine.

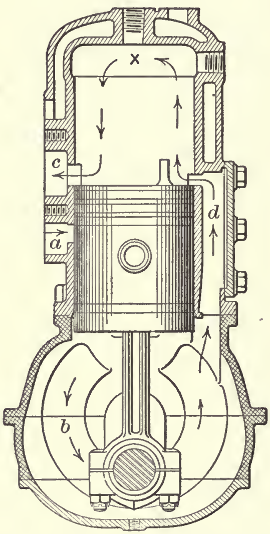


Fig. 91. — Three-port, valveless, two-cycle gas-engine.

out at the exhaust. The return stroke compresses the gas ready for the explosion. An explosion takes place at each revolution or every two cycles.

The explosive mixture is a gas and is a gas after the explosion. The chemical change does not produce any

great change in volume such as would result when a solid changes to a gas, as in explosion of gunpowder. The tem-

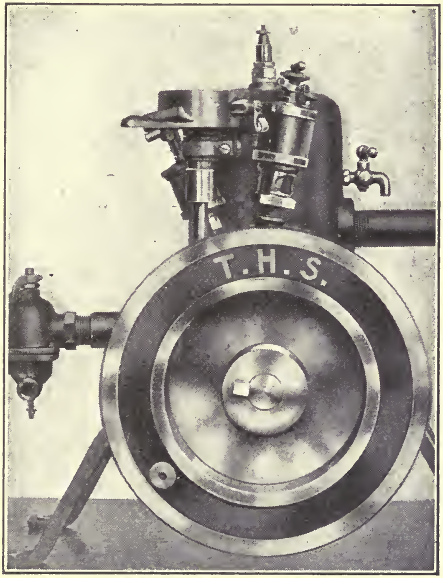


FIG. 92.

Gas-engine, with carburettor, built by a high-school boy.

perature however is changed through a wide range and, since the volume is expanded $\frac{1}{273}$ of its volume at freezing point for each degree Centigrade, it expands violently. This is strictly a heat engine and the hotter it can be run the more efficiently it will work. The limit to the temperature is set by the temperature at which the moving parts will work and can be lubricated.

For finding the horse-power of a gas-engine the most accurate method is the Prony brake. A special form of

indicator is also used to find the mean effective pressure and this is substituted in the formula

$$\text{H.P.} = \frac{PLAN}{33{,}000}$$

The following formulas are commonly used and are approximately accurate. The Association of Licensed Automobile Manufacturers use the formula

$$\text{H.P.} = \frac{D^2 N}{2.5} \qquad \begin{array}{l} D = \text{Diameter of cylinder, in inches} \\ N = \text{Number of cylinders} \end{array}$$

This gives the horse-power only at full speed. Find the horse-power of 4-cylinder engine with 4-inch cylinders.

$$\text{H.P.} = \frac{16 \times 4}{2.5} = 25.6 \text{ horse-power}$$

A formula often used is

$$\text{H.P.} = \frac{SCAN}{12000}$$

S = stroke in inches
C = number of cylinders
A = piston area
N = number R.P.M.

HOT-AIR ENGINE

The hot-air engine has no valves nor ports. A confined quantity of gas is alternately heated and cooled. The resulting expansion and contraction cause changes in pressure which run the engine. It does not work very efficiently, but, because of its simplicity and slight care needed, is much used to run farm pumps. In Fig. 93, heat is applied at *c*, *a* is the working piston fitting tightly in the cylinder, *b* is the displacer fitting loosely. The air becomes

heated and forces a out to position shown in section. The displacer is moved over to position e forcing the air out to

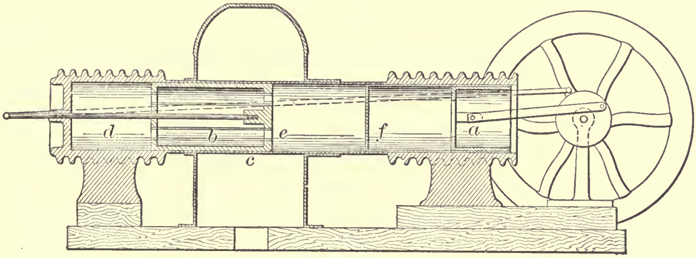


Fig. 93. — Section of hot-air engine.

end d. Here it is cooled, and its contraction allows the outside atmospheric pressure to force the piston back to position f.

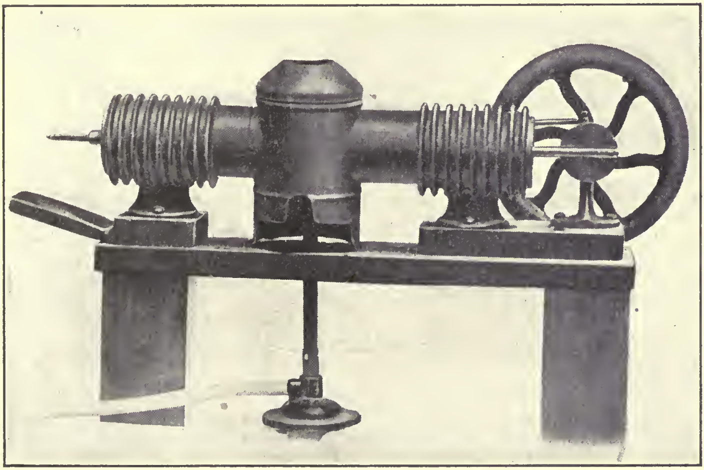


Fig. 94.

The hot-air engine of which section is shown in Fig. 93. There are no valves and few parts to keep in order.

Since heat may be changed to other forms of energy and other forms of energy may be changed to heat energy, it must be that a certain amount of heat is equivalent to a foot-pound of energy. Just before our Civil War, an Englishman, J. P. Joule, after several years of measurements, found that one B.T.U. is equal to 778 foot-pounds of energy. This means that in the metric system, one kilogram calory of heat is equal to 427 kilogram meters of energy. The water of Niagara Falls changes its kinetic energy to heat, and by means of the heat equivalent, it is possible to compute the rise in temperature due to the descent of the water.

If a one-pound weight were allowed to fall freely 778 feet, it would have, at the moment of striking, 778 foot-pounds of kinetic energy. This changed to heat would be 1 B.T.U.

A good grade of coal, such as pocahontas, yields, when burned, about 14,000 B.T.U's per pound. Suppose one pound of coal (14,000 heat value) be used under a boiler and the steam be used to run an engine. The 14,000 B.T.U's are equivalent to $14{,}000 \times 778$ or 10,892,000 foot-pounds. If the combination is working at 10% efficiency this would mean a yield of 1,089,200 foot-pounds of work or the equivalent of one horse-power for 33 minutes.

How many pounds of such coal would be required to melt one ton of ice at 32° F. and change it to steam at 212° F. if 25 % of the heat is lost?

If air weighs .08 pound per cubic foot, how much coal would be required to warm the air of a room $30 \times 50 \times 15$ feet 70° F.?

Heat energy may be carried from one point to another by three different methods. If one end of an iron rod is heated in the forge the other end soon becomes too hot to handle. This method of transmitting heat by one molecule heating the next one is conduction. A glass rod

may be held in the hand while the end a few inches away is melted. If rods of silver, copper, iron, and brass are heated at one end, the heat will not travel along them at equal rates. Most of the metals are good conductors. Silver and copper are the best, while iron is not so good and glass is almost a non-conductor and air and water are very poor conductors of heat. A copper boiler is better than an iron one for boiling the clothes as it will conduct the heat better. For the same reason a copper teakettle is better than an iron one.

When air is heated it expands and is therefore lighter than cooler air. If the air in one part of the room is heated it will be forced up by the heavier air crowding in to take its place. If a lighted match is held over a radiator, rising currents of air will be found. Near the floor, currents of air toward the radiator, and near the top of the room currents of air away from the radiator will be shown. These are convection currents. The draft of a chimney, the air rising in a hot air furnace, the trade winds and nearly all our terrestrial winds are convection currents. The hot water heater is a good example of heat transmission by convection currents.

In the last two paragraphs, we found that heat is carried from one place to another along a continuous solid by conduction and from one place to another by convection currents, as in the hot water heater when water is heated in the boiler by contact and then carried along by convection currents to heat radiator by actual contact. We know that heat is brought to us from the sun, that it travels through space where there is no matter to carry it either by conduction or convection. We know that it travels with great velocity and that it comes through the window without warming the glass. This is called radiant heat and is supposed to be waves in ether, as light is, with a longer wave

length. Radiant heat, as waves of ether, travels on with the velocity of light until it collides with some surface which is able to change it to the ordinary form of heat. If radiant heat from the sun strikes a black rough substance like iron, it is changed to kinetic heat. This is called absorption. If the waves strike a polished surface like a mirror they are reflected and pass out again to space. A black suit is hotter in summer than a light colored one because it absorbs a greater quantity of the radiant heat striking upon it. Explain how a greenhouse traps the heat from the sun. Explain why the mountain climber on top of Mt. Shasta must cover every part of his face or it will be seriously blistered, while the snow never melts. Why is the upper air so cold while radiant heat is coming from the sun to the earth? Why does the radiant heat of the sun fail to reach the earth on a cloudy day? Why do we get our early frosts only on clear nights?

We have discussed the change of radiant heat to sensible heat; is the process ever reversed? A glowing grate, glowing coals, or a hot iron will send out radiant heat and in so doing will be cooled. It is found by experiment that a hot body with a black rough surface will radiate its heat much more rapidly than a polished surface. A good radiator is also a good absorber and a poor radiator is also a poor absorber. A black kettle will heat more quickly than a polished one and then when set aside with hot water in it will cool more quickly. A bright polished teapot will keep the tea hot on the table longer than the dingy iron one. This is because the surface is a poor radiator although the silver is a good conductor.

Laying aside art and beauty, the nickel and polish on your heating stove might better be replaced with black iron rough surfaces, as they are better radiators. Why does

snow under a dirty black cover melt before the clear white article does?

Freshly fallen snow is a poor conductor of heat because it has much air confined in the small spaces, and air is a non-conductor where it cannot set up convection currents. Loosely woven woolen goods are poor conductors for the same reason. In hot countries closely woven white goods are worn as they reflect the heat from without and conduct the heat from the body.

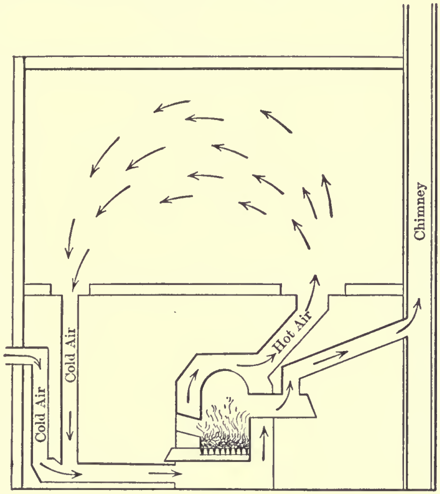


FIG. 95.—Section of hot air furnace.

Study the following and be prepared to report on them in class. Hot air furnaces, steam heating, hot water heat, ice plant, blast furnace, and foundry.

In Fig. 95, transmission of heat by convection currents is shown as applied to the hot air furnace. The fire on the grate in the fire-box heats the gases inside the fire-box to a high temperature. This causes them to expand, and as cold air is heavier than hot air, a "draught" is caused. In other words, the greater pressure of the cold air forces the smoke up the chimney. The air inside the jacket of the furnace is heated and convection currents are set up through the hot air pipes to the rooms above.

CHAPTER IX

MAGNETISM AND ELECTRICITY

Every boy knows that steel treated in a certain way becomes a magnet. If the blade of a knife is stroked by a permanent magnet, it in turn becomes a magnet and will then attract pieces of iron and steel. We will find later that there are other ways of producing the same result. A kind of iron ore, called lodestone (leading stone), possesses the same property of holding small particles of iron. It was early found that magnets, suspended so that they were free to swing toward any part of the horizon, come to rest with one end pointing toward the north or nearly north. This end is called the North Pole. The opposite end is the South Pole.

If one magnet be free to turn and a second is brought near it, the north pole of one will attract the south pole of the other and repel the north pole. *Like magnetic poles repel, and unlike poles attract each other.*

If a long bar of hard steel or a knitting needle be magnetized, and dipped in filings, a point near each end will hold a large bunch of filings, while the middle will hold none. These strongest points are the poles. If a piece of soft steel be brought near a magnet it becomes a strong magnet, but loses its magnetism as soon as the magnet is removed, while hard steel will hold it. If a magnet is placed on a drawing board and a sheet of paper be placed over it and fine iron filings sifted on the paper, they will arrange themselves in lines as shown in the figures below.

Where the unlike poles are presented the lines will appear as in Fig. 96. If the like poles are toward each other

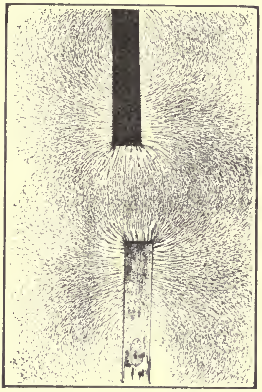


Fig. 96.

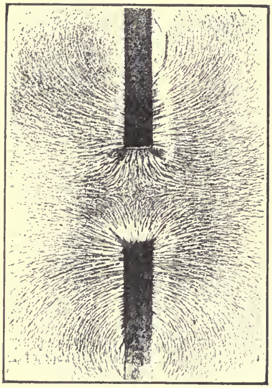


Fig. 97.

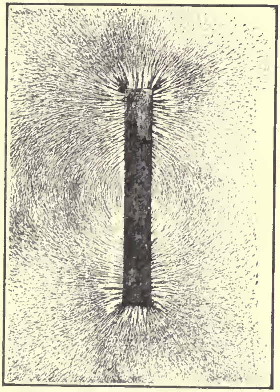


Fig. 98.

the lines run as in Fig. 97, while for a single magnet they run as in Fig. 98. The space filled with these lines around a magnet is called the magnetic field.

The lines of force shown by iron filings in Fig. 96 run between a North and a South pole. These lines seem to act like stretched rubber bands pulling the poles together but the lines repel each other laterally. When two N-poles are presented in Fig. 97 this lateral repulsion causes the poles to repel each other.

The lines are alike at each pole so far as the filings show them but later study with electrical apparatus will show

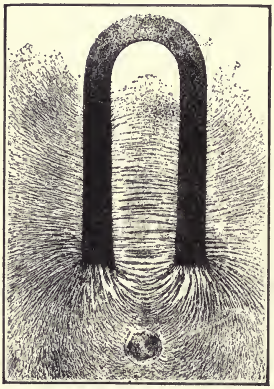


Fig. 99.

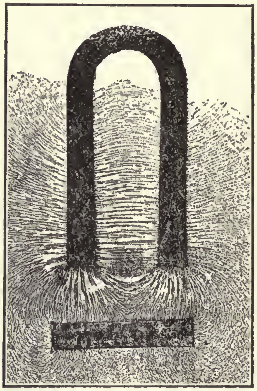


Fig. 100.

that they have direction; therefore they are assumed to pass from the N-pole around through space to the S-pole.

Soft iron within the field becomes a magnet by induction. Note how the lines crowd together in order to pass through the soft iron rather than through air. The soft iron is more "permeable" than air.

Pieces of iron or steel brought within the magnetic field become magnets and are attracted, as in Figs. 99 and 100. These also show the lines of force to be gathered in more thickly by soft iron as they find it easier to pass through

iron than through air. The electrician says the soft iron is more permeable than air. Glass, paper, wood, and many other substances brought within the magnetic field are not affected by it and apparently produce no effect on the field, as the lines seem to run through them as well as through the air. A few substances such as antimony and bismuth are repelled by a magnet. We will find, as we take up the study of electricity, a very close relationship between electricity and magnetism, and the facts about magnets will constantly be used in the study of electricity.

THEORY

The statements of the last few paragraphs are observed facts. The statements made in this paragraph are pure theory used to explain those facts and may be changed any day. There are now several other theories about equally as good and you must feel free to accept this theory or some other, or to reject all of them as you choose. We feel that the next few years may see some discoveries which will reveal the true nature of magnetism and electricity. It is supposed that in a piece of steel, each molecule is a magnet with a north pole and a south pole. If the molecules are arranged without any order, some one way, some another, like a mob, the north poles of some are balanced by the south poles of others and the pieces of steel will show no magnetism. Let a magnet be brought near and the molecules will line up like a column of well-drilled soldiers, and all of the north poles will be in one direction and all of the south poles in the other direction, and the whole piece will show at one end a north pole and at the other a south pole. In the middle the poles will balance each other, but, if the magnet is broken, each half will be found to be a magnet. A piece of hard steel will hold its molecules lined up and hence hold its magnetism, while

a piece of soft steel will let them rearrange themselves so that it will not hold its magnetism.

The ether in the space surrounding a magnet is supposed to be under a strain, and this strain reveals itself in the so-called lines of force shown by the iron filings near a magnet. These lines of force are said to begin at the north pole and pass around to the south pole, then through the magnet to the place of beginning. They act as stretched rubber bands which tend to shrink to zero length. They repel each other laterally and try to get as far apart as they can. How nicely this explains the attraction of unlike poles and the repulsion between like poles of Figs. 97 and 98. But do not forget that this is theory and so far has never been proved.

The earth is a great magnet. When iron filings are placed near a bar magnet each piece of steel arranges itself with its length in one of the lines of force. A magnetic needle free to turn does the same thing in the earth's field. We say the needle points north. This is not strictly true. The north magnetic pole and the geographic North Pole found by Peary are not at the same place. The magnetic pole is about 1000 miles south of the North Pole, at latitude 70° North, longitude 97° West, north of Hudson Bay. The needle does not always point in the same direction but slowly changes its direction through a long period of years and then swings back again. A needle free to move in a vertical plane will not remain horizontal but will "dip," that is, its north end will drop down. At the magnetic pole the needle stands in a vertical line.

ELECTRICITY

At the present time scientists do not know what electricity is. Electricians know a few things about it and may know some day what it is. It is closely related to light on one hand and magnetism on the other, and these things

lead us to think that it may be some kind of disturbance or strain in the ether, or it may be something always accompanied by a strain in ether. If this strain is communicated to one part of a body made of certain material, such as copper, the electricity is distributed to all parts of the surface. Such a substance is called a conductor and the electric strain while being transmitted is called an electric current.

We have mapped the magnetic field around a magnet and have seen how something which we call lines of force fills the space near a magnet. If a loop of wire or any conductor of electricity is placed within this field some of the lines of force will pass through the loop; we might say they link with the conductor. If by any means the number of lines of force linking through the loop of the conductor is changed, an electric current is set up. We may cause this change in the number of lines of force in several ways, by revolving the loop of the wire, by moving the loop, or by moving the magnet. The result is the same in all cases. That is, if a conducting circuit be placed in a magnetic field, and by any means whatever the lines of force threading through it be changed, an electric pressure is caused in the circuit, and the electric pressure is proportional to the rate of change of the number of lines of force.

The terms, pressure and current, have much the same relation to electricity that they have to water pressure and flow of water. When considering fluids, the pressure was found to be proportional to the depth. If a long horizontal pipe be tapped into the bottom of a water-tower or stand pipe and the opposite end be left open the flow of water depends upon the pressure and the size of the pipe, that is, upon the resistance it offers to the current. The pressure gauge also shows a fall in pressure from the end at the tower along the pipe to the open end. The rate

of flow is the same in all parts of the pipe but the pressure falls. The same terms, pressure and current, are applied to electricity. The pressure may also be called potential, Electro-Motive Force, or (E.M.F.). The fall in potential along a conductor may be called line drop or difference in potential. In discussing the loop of wire it is important to state that the pressure is proportional to the rate of change in the number of lines of force; the current depends both upon the pressure and the opposition to its flow or resistance.

In Fig. 101 a magnetic field is shown with lines of force running from north pole to south pole through a rectangle of wire which may be turned by a crank. If the loop is revolved toward the right, the number of lines of force through it will fall to zero. Then as the loop revolves farther the lines of force will pass through in the opposite direction and increase until all the lines run through in the opposite direction. They will fall again to zero and increase to the full number, as in the figure, when the rectangle has made a complete revolution. The effect would be exactly the same if the loop of wire were held stationary and the magnets revolved about the loop so that the lines of force passed through the loop first in one direction and then the other. We have said that the electric pressure developed is proportional to the rate of change of the

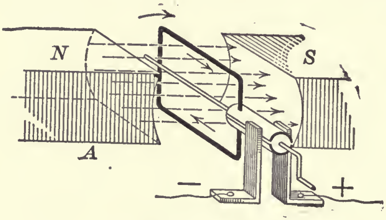


FIG. 101.

If the loop of wire revolves, the number of lines of force through it is changed; in other words, it cuts the lines of force. This cutting of the lines of force develops an electrical pressure. Since the invention of the Edison dynamo in 1881, most of the electricity used is generated by this process.

number of lines of force. Careful observation of the rectangle will show that the change of lines of force is first one way and then the other, and both mathematical demonstrations and experimental measurements show that the electric pressure follows the same change as in Fig. 102, that is, a pressure first in one direction and then the other following wave lines as in Fig. 102. Such a current, first in one direction and then the other, is called an alternating current or A.C. If wires are connected to the ends of

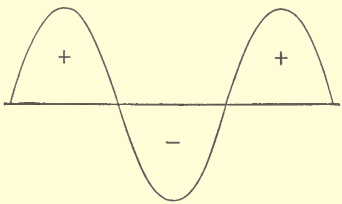


FIG. 102.

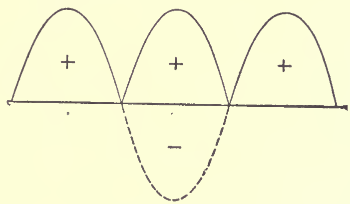


FIG. 103.

The pressure generated in the loop of Fig. 101 follows the sine curve shown in Fig. 102. It is proportional to the rate of cutting lines of force at each point of the revolution. The commutator changes the direction of each negative loop as in Fig. 103.

the rectangle by slip rings and led away to form a circuit, the wire would carry A.C. electricity. Such a current is used for ordinary incandescent lighting. We will later study the advantages and disadvantages of A.C. distribution.

If two pieces of copper are attached to the ends of a loop and two brushes set to slide on the pieces of copper as shown in Fig. 101, in such a way that just as the current is about to reverse in the loop each brush slides over onto the other piece of copper, the current in the outside wire will flow in the same direction it did before and will be like the line in Fig. 103. This current, since it is all in one

direction, is called a direct current or D.C. If more loops are put on so that while the current of one loop is low, another loop is supplying the needed pressure, the curve becomes that of Fig. 104 and we have a D.C. generator such as is used to supply current for motors and lights of this building.

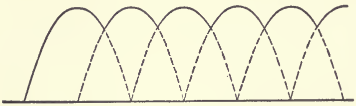


Fig. 104.

The magnets supplying the lines of force are field magnets.

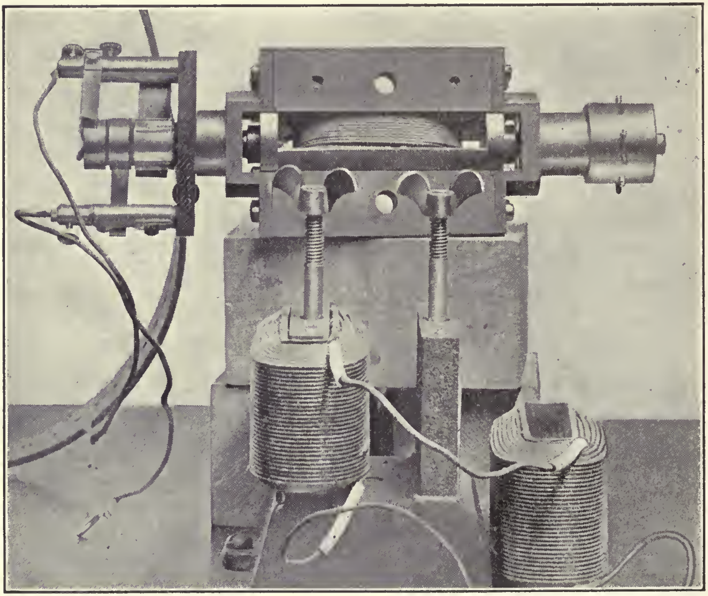


Fig. 105. — Dissectible Hand Dynamo.

The loop of wire is revolved at high speed (3500 R.P.M.) between the poles of a strong magnet. A soft iron core insures a large number of lines of force for the conductor to cut.

The pieces of copper for changing or commuting the current to make it direct are the commutator.

The loop of wire in which the electric pressure is developed is called the armature. Either field or armature may be revolved. The electric pressure is commonly called

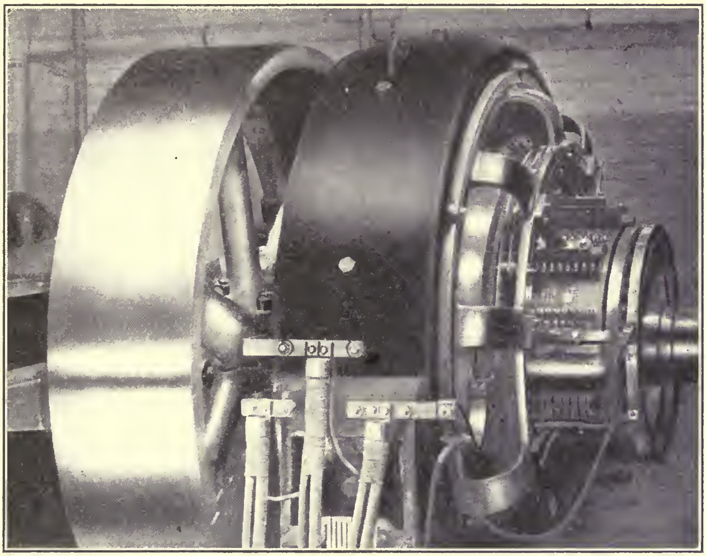


Fig. 106. — 300 Horse-power D.C. Dynamo.

One of two used at Technical High School, Cleveland. This machine makes 600 R.P.M., and at each revolution each conductor cuts the lines in front of 14 poles.

electro-motive force or E.M.F. and is measured in volts which we will define later. The quantity of current set up is measured in amperes which we will also define later.

A magnetic needle comes to rest with its north pole pointing almost north. If a wire carrying an electric current is brought down near it and parallel to the needle

as in Fig. 107, the needle will swing from its former position and come to rest at an angle to the wire. If the direction of the current in the wire is reversed, the needle will be deflected in the opposite direction. We speak of the direction of the current as though we knew. Electricity may be some sort of a strain in ether and when that strain is transmitted from one point to another we call the connecting substance which distributed the strain a conductor, and not knowing any better term to use, we call the flow of electricity a current. For convenience in studying some of the applications we say the current flows from the positive (+) to the negative (−) side. It must be understood that this is only a convention, although a useful one. With the wire above the needle as shown, if the right hand is brought down with the palm of the hand toward the wire and the fingers pointing in the direction of the current, the extended thumb indicates which way the north end of the needle will move.

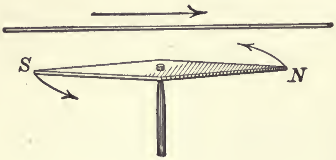


FIG. 107.

The copper is non-magnetic, but when a current of electricity flows over the wire the needle tends to turn at right angles to the wire. This shows a magnetic field about a current of electricity.

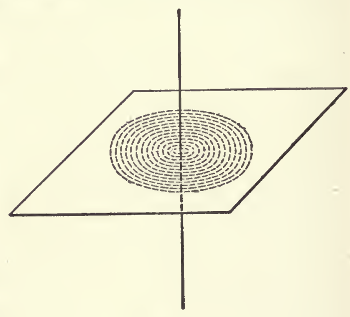


FIG. 108.

Concentric rings show the field around a wire carrying a current of electricity. Six amperes or more are required to arrange filings.

The above results lead us to suppose that there is some magnetic field around the wire when the current is flowing.

To test this we run the wire through a piece of paper and scatter iron filings around it. When a current flows though the wire, the filings arrange themselves in concentric rings about the wire as a center. These rings show lines of force in the space about the current, Fig. 108. Grasp the wire with the right hand with the thumb in the direction of the current and the fingers will show the direction of the lines of force. Make a helix or coil of the wire as in Fig. 109 and apply the same rule for grasping

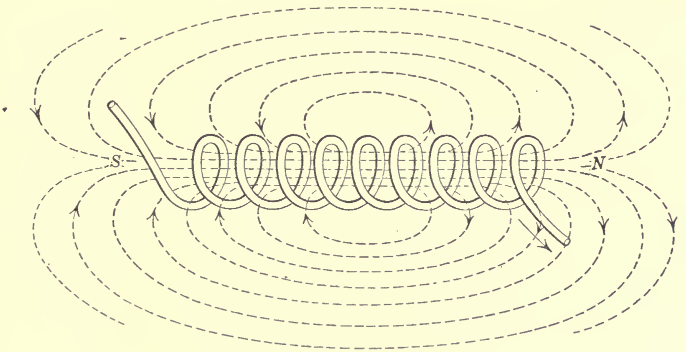


Fig. 109.

the wire and we will find that the lines of force of each turn of wire tend to strengthen those of the others. Grasp the coil with the right hand with the fingers along the wires in the direction of the current and the thumb will indicate the north pole. When studying the magnetic field, it was found that the lines of force pass through iron much more readily than through air, and we find by experiment that if a soft iron core be placed in the coil of Fig. 109, a current which would before produce only a few lines of force will produce a large number through the iron, and a strong magnet will result, see Fig. 110. This is an electro

magnet. We shall now take up some of its applications, which cover a large part of the field of applied electricity.

When a current of electricity flows through the wire coil or helix described in the last paragraph, the coil becomes a magnet with a north pole and a south pole, like any other magnet. When a core of soft steel is inserted through the helix the strength of the magnet is greatly increased, for the reason that the soft iron lets the lines of force pass through more readily than the same space containing wood or air or any other non-magnetic substance. Soft iron is more permeable than hard steel; hence while the current flows, the soft iron core is a stronger magnet than the hard steel. As soon as the current is turned off the soft iron loses most of its magnetism. The Morse telegraph instrument depends upon this principle. A bar of soft iron is held in place above an electro magnet by a spring. The electro magnet is connected to a circuit from a distant station where a current is furnished either by a dynamo or a battery. As the earth is a good conductor the return wire may be replaced by the earth. Any wire offers some resistance to the flow of an electric current, so the current carried by a wire for long distances is too small to make the sounder work as well as it should. Therefore, a relay is put in and acts as a key to work a local

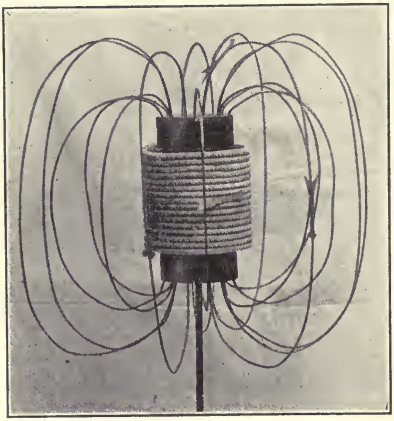
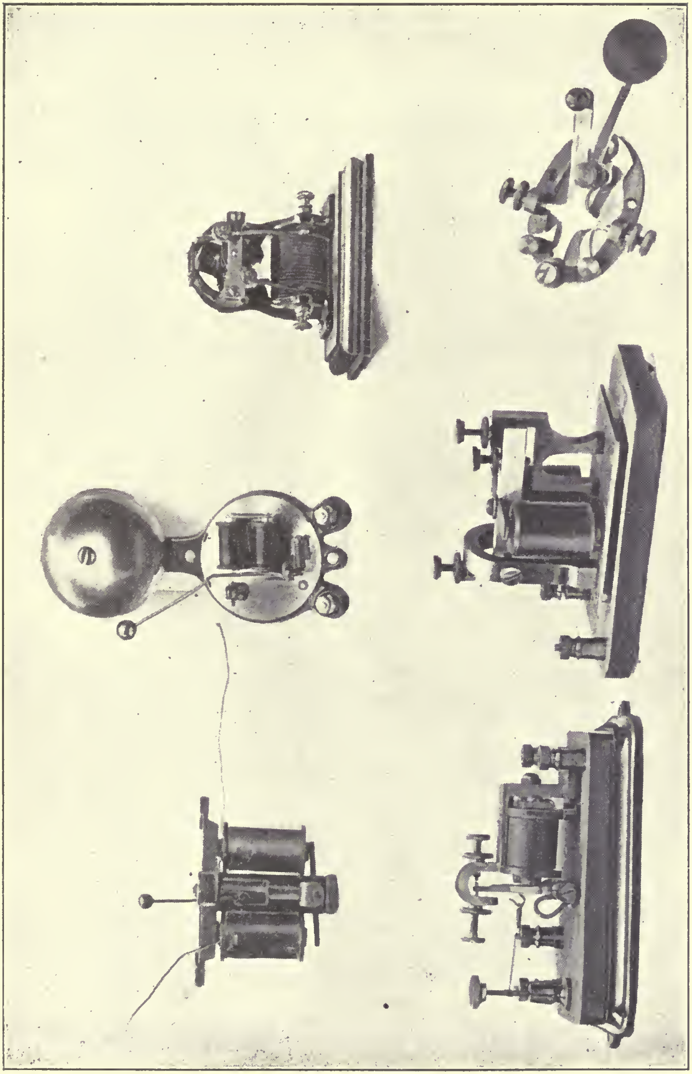
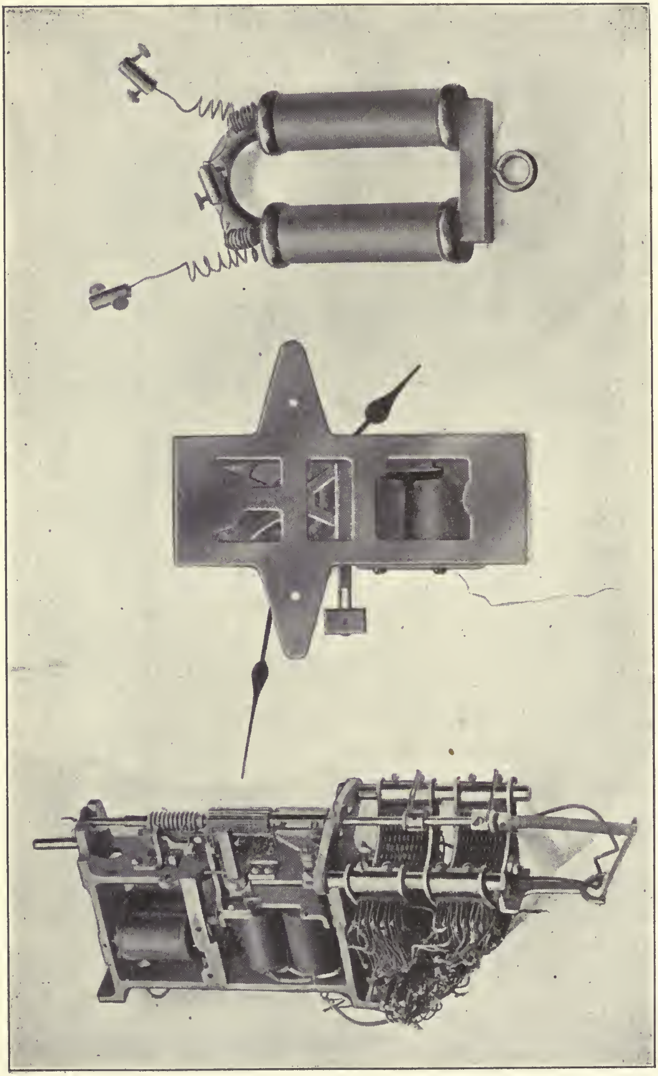


Fig. 110.



Magneto, A.C., Bell Ringer. Door Bell. Toy Motor.
Telegraph Relay. Telegraph Sounder. Telegraph Key.

Fig. 111. — Applications of the Electro Magnet.



Automatic Telephone Switch. Electric Clock. Electr. Magnet

FIG. 112. — Applications of the Electro Magnet.

circuit. The connection for the sending and receiving station is then as in Fig. 114.

The key at Chicago is pressed and the current flows through each relay on the circuit and each sounder is

FIG. 113. — Lifting Magnet.
Two tons of scrap iron are transferred at each lift by this magnet.

pulled down and held as long as the sending key is pressed. Dots and dashes are used to represent letters.

T	E	C	H	N	I	C	A	L
–	.	. . .	. . . .	– .	. .	. . .	. –	—

spells Technical.

The door bell is also an application of the electro magnet. The circuit is wired as in Fig. 115. When the key or button K is pressed, the circuit is completed and the current flows through the electro magnet m, pulling the armature up and striking the bell. At the same time the circuit is broken at O, the current stops, m is no longer a magnet

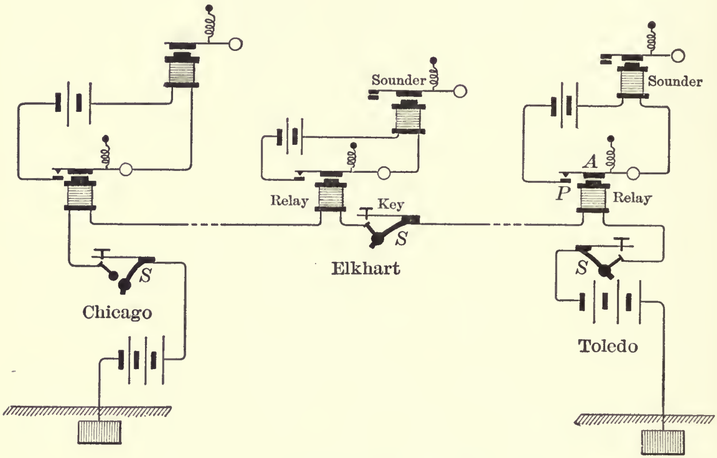


Fig. 114. — Morse Telegraph Circuit.

Chicago sending. Every time this key is pressed every relay and every sounder on this line clicks the same signal.

and the soft iron armature falls back to B and the process is repeated, ringing the bell as long as the button is pressed. The contacts in K and O are likely to get dirty or covered with oxide and prevent the working of the bell. They should then be scraped clean. If the battery is composed of dry cells, they will need replacing occasionally, or if a sal-ammoniac battery is used, the solution will need renewing when exhausted. Aside from this slight attention the bell needs no care.

We will now take up the study of another application of the electro magnet, the motor, which is much in evidence every day. In the instrument known as the D'Arsonval galvanometer, a coil of wire is suspended by a tape of phosphor-bronze so that the coil hangs between the poles of a permanent magnet with the axis of the coil at right angles to the lines of force of the field in which it hangs, as in Fig. 116. A spring below the coil serves as a conductor to complete the circuit and also to hold the coil in place. When a current is sent through the coil it becomes a magnet, according to the law of magnets; the north pole is attracted by the south pole of the permanent magnet and repelled by the north pole. The south pole of the coil is pulled in the opposite direction so that the coil swings about in its field, and the amount of the deflection depends on the strength of the current. If the current is strong enough the coil will turn at right angles to its first position or until its north pole is toward the south pole of the magnet. If the current continues to flow in the same direction and the coil is turned beyond this position, the magnetic drag will stop it and

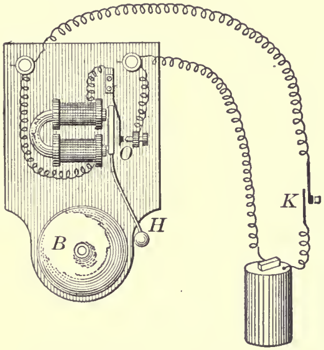


FIG. 115. — Electric Bell.

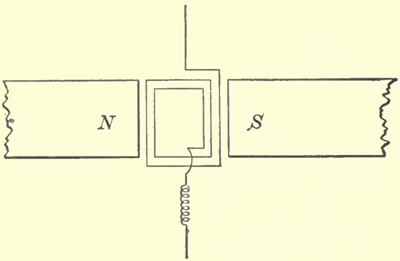


FIG. 116.

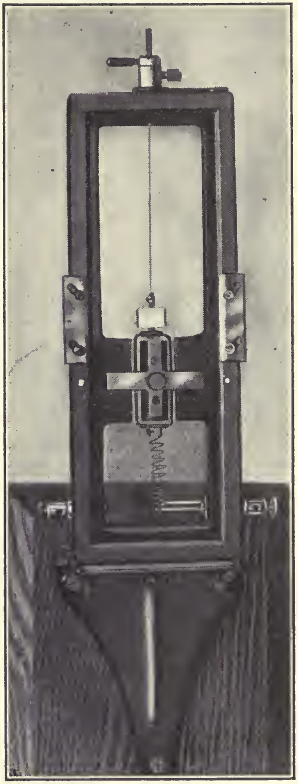


FIG. 117. — Galvanometer.

The frame is a strong permanent magnet. The coil is copper wire wound on a brass frame. It is non-magnetic except when a current of electricity passes through it, then it indicates the current by turning toward one side.

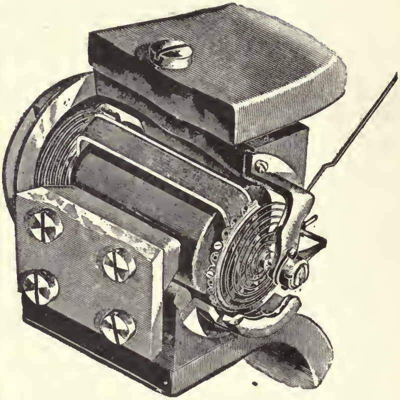


FIG. 118.

The D'Arsonval Galvanometer as used in the D.C. Voltmeter. The movable coil is carried on jewel bearings. The scale is read in volts.

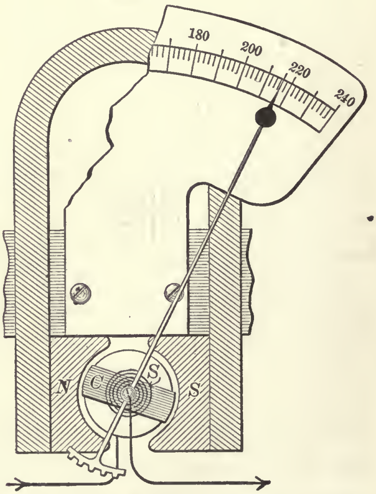


FIG. 119. — Section of the D'Arsonval Galvanometer, used as a Voltmeter.

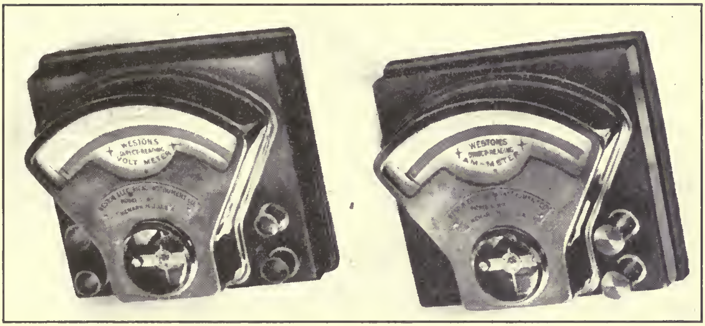


FIG. 120.
Weston Voltmeter and Ammeter, galvanometers with other names.

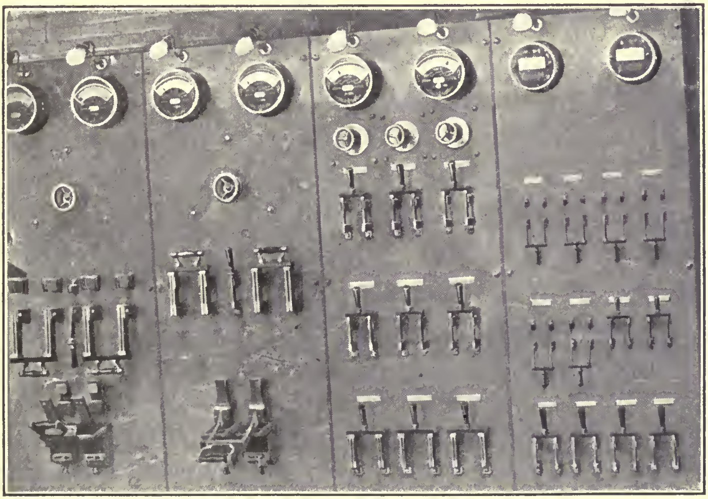


FIG. 121. — Switch Board.
Voltmeters and ammeters in use on a distributing switch board.

bring it back. If the current is reversed just as the coil reaches the position where it would stop, the inertia carries it beyond; the magnetism of the coil being

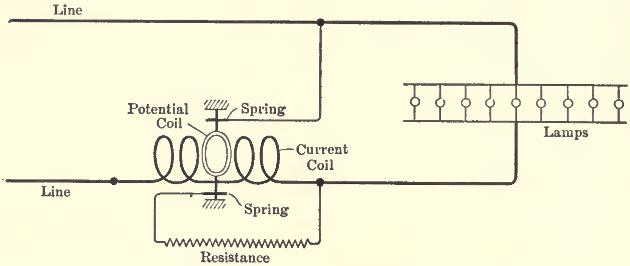


Fig. 122. — Direct Reading Wattmeter.

The current coil carries the current while the potential coil carries a current proportional to the pressure. The reaction between the two measures the product of the volts times the amperes, thus it is read in watts.

reversed, the permanent magnet swings it on the rest of the turn. If this were continued with a galvanometer, it would soon twist off the supporting tape. By putting the coil on bearings and making the electric connection through brushes and commutator as in the dynamo shown in Fig. 101, the current is carried to the coil by a sliding contact. The magnetism of the coil is reversed at the proper time to keep it going, and we have the principle of the common direct current motor such as run the street cars of the city.

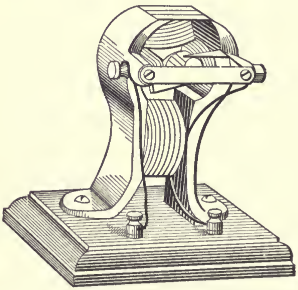


Fig. 123. — Toy Motor.

Again the principle of the galvanometer is applied, although the name is changed.

Do not fail to note that in the electro magnet there are two distinct circuits: the electric circuit, which is of copper wire, with each turn insulated from the iron core and also from the other turns; and the magnetic circuit, which is of soft iron, and should have as little air gape as possible for the lines of force to pass through, since iron will allow many more lines of force to pass for the same current than will air.

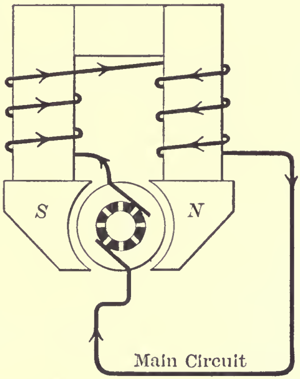


Fig. 124. — Series Dynamo.

The field magnets of the dynamo and of the motor are usually electro magnets and in the dynamo may be energized by a current from the dynamo itself (self excited) or by current from another source (separately excited). When the field of a dynamo is connected, as in Fig. 124, so that the current all runs through the field, then through the load and back to the other brush, it is "series wound" and large wire must be used. With the external circuit open such a field has no current through it, and if volts are plotted on one axis and amperes on the other the voltage starts at a very low point, as *a*, Fig. 125. If more load is now added to the external circuit by turning on more lamps, the voltage builds up along the curved line *ab*. If the field is connected so that the current opposes the residual magnetism, the series dynamo will fail to build up and

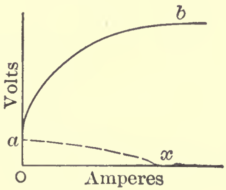


Fig. 125.

will follow the dotted line *ax*. If a series dynamo fails to "pick up" when the contacts are all tight, it is usually necessary to reverse the field.

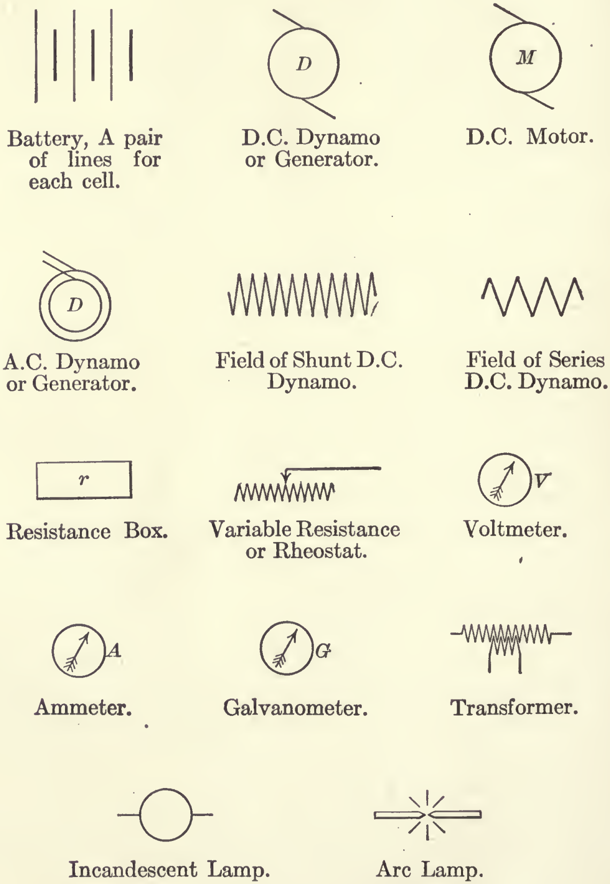


FIG. 126. — Symbols Used in Electrical Diagrams.

In Fig. 127, the connection is shown for the "shunt dynamo." Whenever an electric circuit is connected so that the current may divide and flow through two paths, the connection is called shunt or parallel. In the shunt dynamo the current divides at one brush, part going through the field to the other brush and part through the external circuit back to the second brush. If this generator be run at a constant speed, the highest voltage will be reached when there is no external load and all the current is used to excite the field. As the external load is increased the voltage will drop along the curved line *ab*, Fig. 128. Note from this curve that the shunt machine fails completely under too heavy a load. A resistance in series with the

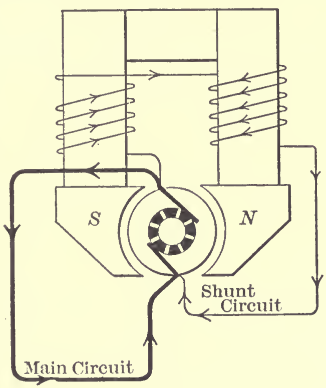


Fig. 127. — Shunt Dynamo.

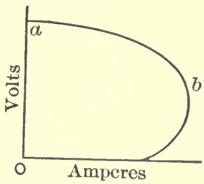


Fig. 128.

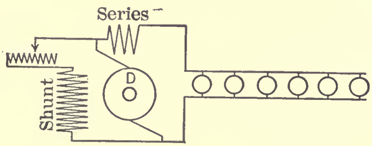


Fig. 129. — Compound Dynamo.

field must be put in to adjust the field strength as the load is thrown in. For lighting and power purposes a constant voltage, usually 110 or 220 or 500, is wanted at all loads. In the series machine the voltage rises higher as more lamps are thrown in, while in the shunt machine, unless an operator stands constantly at the regulator to

regulate it, the voltage falls as more lights are cut in. Fig. 129 shows a connection in common use where both

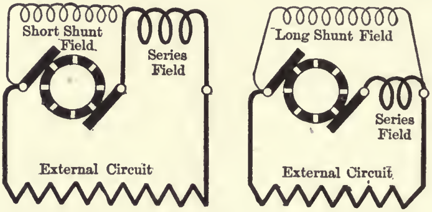


Fig. 130. — Short Shunt and Long Shunt, Compound Dynamo.

series and shunt windings on the same magnets are used, and one picks up as the other decreases so that the voltage remains constant, as is shown by the dotted line *ab*, Fig. 131. This machine is self regulating and is compound wound. The greater part of the electric power generated and distributed to-day is *AC*, but in order to define the units used, we will now take up a brief study of the chemical relation of the electric current before studying the alternator and transformer.

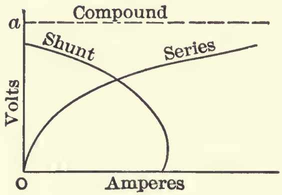


Fig. 131.

THE CHEMICAL RELATION OF AN ELECTRICAL CURRENT

Experiments in the chemistry course have demonstrated that pure water is a non-conductor of electric currents. When a little H_2SO_4 is added to the H_2O in dilute solution the electric current passes readily through it. Many salts in solution produce the same effect. It is supposed that when a salt is in the solution some of the molecules are separated into atoms or groups of atoms, each with a small quantity of electricity, together called ions. Until recently

this was mere theory with little to prove it, but within the last year no less than six different experimenters have actually measured the quantity of electricity carried on the atom and the results by all these methods are about the same. When an electric current passes through an electrolyte (as the solution is called), these ions pass across from one wire to the other through the solution and each carries its little load of electricity and dumps it just as a laborer pushes his wheelbarrow load of sand and dumps it onto a pile. A good union man will push only a certain size load and will refuse to move if he has one extra shovelful. These ions are the best union men there are, as every univalent atom carries exactly a certain amount of electricity, no more, no less, and every divalent atom carries twice as much and they never make a mistake.

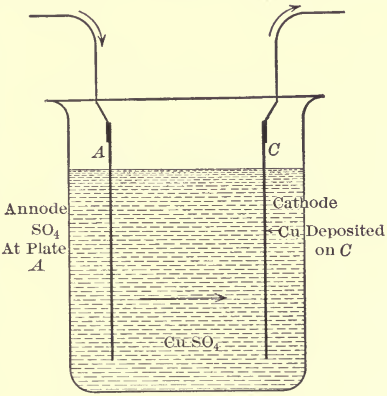


Fig. 132. — Electrolytic Cell.

When a current is forced through the cell the electrolyte is broken up and *Cu* is plated on the cathode.

When the ends of two wires connected to an electric circuit are placed in an electrolyte the circuit is completed through the solution and the ends are called the electrodes. Sometimes they are called anode (the way in) and cathode (the way out). The electrolytic cell of Fig. 132 is shown connected to an electric circuit with pressure enough to drive the current through the direction shown. The action all appears at the electrodes and not in the solution between. The *Cu* atom with its charge migrates to the plate *C*,

where it gives up its charge and is deposited as copper on the plate. The SO_4 ion migrates to the other plate and is liberated at plate A. If A is of copper the sulphion radical attacks it and forms Cu SO_4. If A is a platinum plate the sulphion ion will take H_2 from the water and liberate O at plate A.

If platinum plates are used and the electrolyte is H_2SO_4, the H ion migrates to the cathode, deposits its charge and is liberated as free hydrogen. The SO_4 ion migrates to the other plate, and since it cannot act on platinum it attacks the H_2O, taking out H_2, and forming H_2SO_4, liberating O. The H_2SO_4 therefore remains the same in quantity while H_2O is used.

Electro plating is done by the method shown above. In Fig. 132, C will be copper plated. If the electrolyte is a solution of silver salt and A is a silver bar, the plate C will be silver plated. The silver and nickel plating industry is of great commercial importance in the manufacturing world to-day. Much of the printing of to-day is done by electrotype.

The type is set and an impression made in wax. The face of the wax impression is covered by a thin layer of graphite to make it conducting and then plated by a layer of metal a little thicker than paper. This would be too thin to use in the press, so it is "backed" by pouring on melted type metal. The electrotype plates so made are an exact copy of the type and may be used to print, while the type is distributed and set up again.

We have pointed out that a univalent atom always carries the same quantity of electricity. That is, the quantity of an element deposited by a current passing through an electrolyte is directly proportional to the quantity of electricity passing through it. In dealing with the flow of electricity, through an acid for instance, the

quantity of hydrogen deposited is independent of the kind of acid and its concentration, but depends on the quantity of electricity only. If the same quantity of electricity is passed through different electrolytes the quantity of the substance deposited is proportional to the atomic weight for a univalent element. Each atom carries the same quantity every time. This fact furnishes a means of defining the unit current. The cathode is weighed, and then after an electric current has been passed for a given time, the increase in weight will indicate exactly how much electricity has gone through the circuit. The International Congress defined the **ampere** as: "**The constant current which will deposit 0.001118 grams of silver or 0.0003287 grams of copper in one second.**" This is 4.025 grams of silver per hour.

The same congress defined the **ohm** as "**The resistance offered to a constant current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass of a constant cross section and 106.3 cm. in length.**"

It defined the **volt** as "**That electric pressure which will force a current of one ampere over a resistance of one ohm.**"

A **watt** is **the power to supply one ampere with a pressure of one volt.** These international units are those used in common electric practice in this country. The unit used in selling electricity is the kilowatt-hour, that is, 1000 watts for one hour (746 watts are equal to one horsepower, that is, one kilowatt is equal to about 1.3 horsepower).

BATTERIES

There are a large number of battery cells but we will here consider only a few, the simplest voltaic cell and the one representative of each of the types of cells in most com-

mon use. As the simple voltaic cell will be studied with some care in the laboratory, this description may be brief. A simple voltaic cell may be made of a glass of salt water, a piece each of zinc, copper, and wire. Usually a diluted solution (about one part in twenty) of H_2SO_4 is used. When these are not connected a few bubbles will rise from the zinc. If the zinc plate is amalgamated with mercury no action will take place. If now the two strips are connected by a conductor, bubbles will rise freely from the copper strip. A test will show that these bubbles are hydrogen, that an electric current is flowing along the wire, and that the zinc is used up, that is, changed to $ZnSO_4$. The electric current is set up at the expense of the chemical energy. The action of the ions is similar to that of the electrolitic cell described, but in the opposite direction. If the zinc is not amalgamated, the action goes on at the zinc plate between points of different degrees of purity independently of the electric circuit. Such wasting of the zinc is called local action.

If undisturbed, hydrogen bubbles soon coat the copper plate and oppose the flow of the current. Often this **polarization** nearly stops the action of the battery.

OPEN CIRCUIT BATTERIES

There are two batteries (the NH_4Cl cell and the dry cell) in common use, which if used continuously for a short time will polarize. If connected to a lamp or a small motor they will work for a short time until the collection of hydrogen stops the action. The battery must then rest while the hydrogen disappears. On a door bell circuit which is closed only occasionally and then for a short time such a cell is all right, and for that reason is called an open circuit battery. The NH_4Cl, ammonium chloride or sal-ammoniac cell, is made by placing in a glass jar a solution of NH_4Cl, and in this a carbon with a large fluted

surface and a heavy piece of zinc are placed. The large surface of the carbon reduces the speed of polarization. Often the carbon is hollow and packed with graphite and MnO_2, to further absorb the hydrogen.

In the dry battery the zinc is the jacket of the cell and the electrolyte is made into a paste and the whole sealed by covering with wax. The basis is usually NH_4Cl. If the cell is not used it dries out until the resistance of the paste becomes so large that no current flows. Until the zinc is used up, such a cell may be renewed by injecting a weak solution of NH_4Cl or dilute HCl.

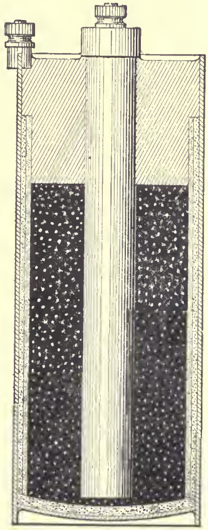


FIG. 133. — Section of a Dry Cell.

The zinc container is one electrode. It is separated from the carbon by a paste containing ammonium-chloride. The carbon electrode is packed in a mixture of carbon and manganese dioxide.

CLOSED CIRCUIT BATTERIES

The cells described in the last paragraph work well on the open circuit system, but in closed circuit work such as running motors, small electric lights, or for commercial telegraph work, polarization renders them useless. Polarization is the deposit of hydrogen about one of the electrodes. In several cells such chemicals are used that some other substance is deposited and polarization is prevented. Fig. 134 shows the gravity cell used in commercial telegraph systems. A strip of copper is placed at the bottom in a saturated solution of $CuSO_4$ and near the top a heavy piece of zinc is suspended in a dilute solution of $ZnSO_4$. The heavier solution is at the bottom so that gravity retards diffusion. Some of the molecules of the zinc sulphate are

ionized and the $-SO_4$ ion migrates toward the zinc, deposits its charge, and forms new $ZnSO_4$, while the Zn ion migrates toward the other electrode, meets the $CuSO_4$ and displaces a Cu ion. This migrates to the copper plate and is deposited as metallic copper, while its charge is given to the copper electrode. As the cell is used the zinc "crowfoot" is consumed, the solution of zinc sulphate becomes more concentrated, the copper sulphate becomes dilute, and the copper plate grows by deposit of pure copper. New "blue rock" must be added and the zinc sulphate solution must be diluted to keep the cell in good condition. To prevent diffusion the circuit *must* be kept closed.

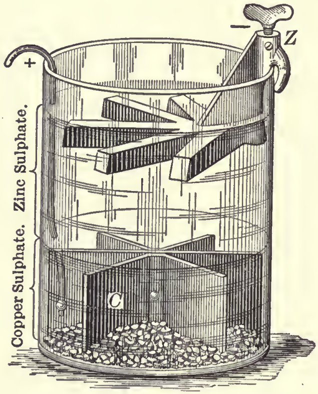


Fig. 134. — Gravity Cell.
This is a closed circuit cell. Used in telegraph work.

The cell just described has so many advantages in the way of furnishing a constant pressure, while being used to furnish a constant current, that a portable form is desired. The result is the Daniel Cell. Exactly the same materials are used, but the zinc is placed in a porous cup containing the zinc sulphate and the cell may be carried about. The action is the same as in the gravity cell.

The storage battery is one of great importance in the present age of electricity. A home-made storage cell for every boy is shown in Fig. 135. Any glass jar may be used. A small one may be made in a ordinary drinking glass. Two lead plates fastened by wires to the sides of a stick of wood are suspended in a 10% to 20% solution of H_2SO_4. If A and B are connected to a suitable source of elec-

tricity a current will flow through the electrolyte and hydrogen will escape at the negative plate, but the oxygen, instead of escaping at the positive plates, unites with the lead forming a brown-colored coat of PbO_2. After the electrolysis has been carried on for a time the circuit may be disconnected and a bell, if connected, will ring. Test will show the current going through the cell in the opposite direction. While the discharge is going on the lead peroxide formed during the charge is reduced to soft sponge metallic lead, while some lead sulphate is formed on the other plate. When the cell is charged again the hydrogen reduces this lead sulphate to spongy lead. Two plates like those shown will not take a very large charge, as only a small amount of the "active material" will be held by each plate. After several charges the cell will work better than at first, as more of the plate has been changed to the active spongy form.

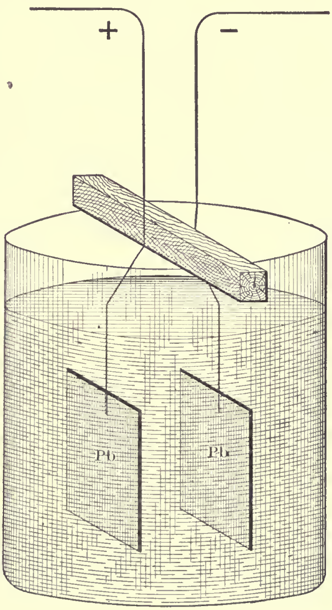


Fig. 135. — Toy Storage Cell.

Forcing a current of electricity through this cell stores up chemical energy. This chemical energy may afterwards be used to generate an electric current.

When the cell is being charged, just as much electricity comes out at the negative plate as goes in at the positive plate. No electricity is stored in the cell, but some of the energy is retained as chemical energy. When water runs down through a water-wheel as much water comes out as goes in, but the wheel takes

some of the energy out. So the storage cell takes some of the energy out but does not store the electricity.

The commercial storage cell has plates of lead bars (Fig. 136), between which are pockets, filled with a paste of the active material, which increases the capacity but not the voltage. The internal resistance is very small, hence a storage battery must not be short circuited.

The lead gridiron plates have little rigidity and buckle easily if they are heated very hot. If discharged or charged too fast the plates heat and buckle, thus short circuiting the cell and destroying it. The jars are glass or hard rubber and easily broken. If the battery is allowed to stand discharged for a few weeks, the lead sulphate formed on one plate during discharge hardens into a white layer which interferes with the working of the cell. Unless the cell is watched and given the greatest care it soon gets out of order. All contacts and metal parts near the battery must be lead covered, to protect them from the fine spray of H_2SO_4 which is carried into the air by the escaping gases.

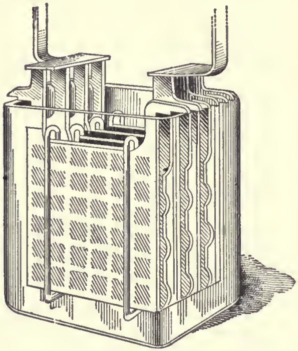


FIG. 136. — Lead Storage Battery.

The lead grid plate contains the paste of "active material" in its pockets.

Thomas A. Edison, after several years' constant effort and thousands of experiments, has produced a storage battery which in many respects is far ahead of the lead storage cell. The jar is of nickle plated steel, thus doing away with breakage. The plates have a frame work of steel which will not buckle even on short circuit. The electrolyte is a solution of KOH, hence no corrosive fumes

are formed. One plate consists of a gridiron of steel with a paste of iron oxide in the pockets. The other plate is a frame work of steel carrying steel tubes about the size of small lead pencils. These tubes are perforated and contain alternate layers of nickel oxide and nickel, the nickel being for the purpose of making the mixture conducting. The battery weighs about half as much as the lead battery of the same capacity. It is free from corrosive fumes, is almost non-breakable, is not injured by too rapid discharge nor by standing discharged. Its rated efficiency is not so high as that of the lead battery, but in practise it is so difficult to keep the lead battery in good condition that the actual working efficiency is usually higher. The prospect is that the new battery will largely displace the old in a few years. Parts are shown in Fig. 137.

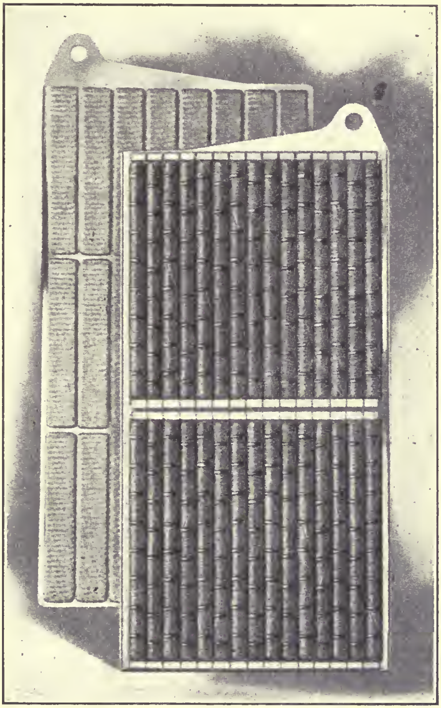


FIG. 137. — Electrodes of the new Edison Storage Cell.

One nickle plated steel plate contains iron oxide in the pockets. In the other plate perforated steel tubes contain nickel oxide.

We have found that the definition of the volt leads us

at once to Ohm's law $C = V/R$, which may also be stated $V = CR$ also $R = V/C$. This gives us one of the commonly used practical methods of measuring resistance. The voltmeter and an ammeter are connected over the resistance as shown in Fig. 138. A current is passed through and the voltmeter and the ammeter readings are taken as near the same time as possible. Then by Ohm's law $R = V/C$. When V is in volts and C in amperes, R will be in ohms. One of the common testing boxes which the lineman carries with him is based on the principle of the Wheatstone's bridge. To understand this it will be necessary to consider divided circuits, which may be called also parallel or shunt circuits.

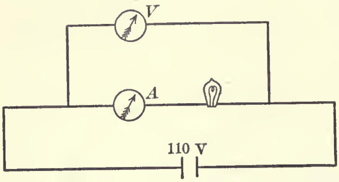


FIG. 138.

Measuring resistance by the use of voltmeter and ammeter.

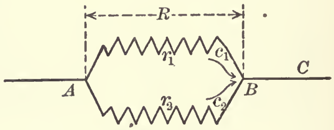


FIG. 139.

Divided circuit, shunt circuit, or resistances in parallel. Part of the current flows over each wire, the larger part in the wire of least resistance.

In Fig. 139 consider two resistances r_1 and r_2 in shunt circuit, with a current C flowing from A to B as shown by the arrows, where c_1 and c_2 are the currents through r_1 and r_2. The fall of the potential from A to B is V volts and is the same by either path; then $C = c_1 + c_2$ but by Ohm's law $C = \frac{V}{R}$; $c_1 = \frac{V}{r_1}$, and $C_2 = \frac{V}{r_2}$; substituting we have

$$\frac{V}{R} = \frac{V}{r_1} + \frac{V}{r_2}.$$

nected to the ends of the interrupter. When the interrupter breaks the circuit the induced electricity, instead of producing a spark, goes to charge the condenser, and as the circuit is closed again the condenser is discharged, helping to build up the current quickly. Hence both changes take place more quickly and the secondary will give a longer spark. See Fig. 145.

An extensively used modification of the induction coil is the transformer. It is said that the reason the moonshiners of the Kentucky mountains are still in existence is that the roads are so bad and railroads so few, they cannot get their corn to market, but by making it into whiskey the bulk of the corn is so much reduced that it is easy to carry out. After getting it to market in this form it is not considered good food for horses. In the case of an alternating current of electricity, such as described on page 133, the current may be reduced to small amperage at high tension for transportation, and then easily transformed to large amperage at low tension for ordinary use. You may suppose that the electric lights in your home are connected with the power plant of the Illuminating Company. They are not. They are completely insulated. To supply 20 amperes at 110 volts to light 40 lamps, only one ampere at 2300 volts is transmitted along the line. The line loss in transmitting the one ampere is much less than it would be to transmit

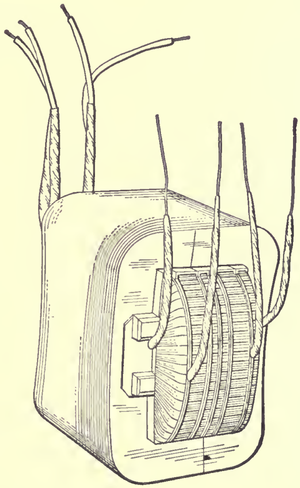


Fig. 146. — Closed Core Transformer.

the 20 amperes and the wire may be much smaller, and at the present prices of copper that is a great item. How is it done? By means of the transformer. Imagine an induction coil with the core extended from one end, around the outside of the coil to the other end, to form a complete return circuit of soft iron for the lines of magnetic force, and you have a good idea of the transformer. In one set of windings there are 20 turns of small wire, for every turn of large wire in the other winding. Either may be used as the primary. Usually the small wire is connected to the 2300-volt feed wires and the large wire to the lighting circuit. If there were no loss in transformation the ratio of the voltages would then be 20/1 and that of the currents 1/20, that is, the watts (amperes times volts) would be the same in both lines. In practise there is from 30 to 10% loss, although transformers have been built which give 98% efficiency. The transformer will not work on a direct current, as the secondary generates an E.M.F. only during a change in the magnetic flux through the coil, and this change takes place only while the current in the primary is either increasing or decreasing. The transformer is used on the alternating current following the curve shown on page 133. In common practise, the lighting transmission lines are 2300 volts and the current makes 60 cycles or 120 alternations per second. For long distance transmission high tensions are used. The Sanitary District of Chicago generates power 38 miles from the city at 11,000 volts, steps it up to 66,000 volts, transmits it on bare wires to Chicago and steps it down to 110 volts for use. Some lines transmit power at 100,000 volts. In one of our large cities a 2300 volt lighting wire fell across a telephone wire and before the " trouble shooter " could locate and correct it several people were killed by shocks from telephones. It is important that wherever such lines cross

they should be protected by automatic devices which will cut them out of the circuit if anything happens to the line. A person with dry feet standing on a dry floor may handle *one* side of a 2300 volt circuit with bare hands without danger, but he must not ground the circuit or connect the two lines through his body.

We are now ready to take a more complete survey of the lighting system of a modern city. For street lighting, the system still in common use is the open arc with the lamps in series. Such lamps require about 45 volts for each lamp and an average of 5 volts for line drop, making 50 volts for each lamp. 100 lamps are connected in series and operated by 5,000 volts D.C. constant current dynamo. The current for most cities is maintained at 6.6 amperes, although some use 9.6 amperes. Such lights rate at 1,200 and 2,000 candle-power respectively. They should never have been rated so high, as they actually give only from 375 to 450 candle-power. The demonstration with the lead pencil arc has shown that, when turned on, the carbons must be in contact and then drawn apart to "draw out the arc." As the carbons are burned away under the heat of the arc, one or both must be fed forward. Both these movements are accomplished by means of the electro magnet. The coils of large wire, *S*, Fig. 147, is in series with the arc. The sliding brush, *B*, forms contact with the brass rod carrying the upper carbon. When the key, *K*, is opened the current flows through the coil, *S*, and lifts the armature, pulling the upper carbon with it by means of the loose clutch, *A*. The coil, *C*, is of small wire with a high resistance and takes very little current while the arc is short, but as the arc increases in length by the burning of the carbons the resistance becomes greater. The dynamo is all this time forcing a constant current through the lamp so that the strength of the magnet, *S*,

stays the same, but the increasing resistance of the arc drives more current through the coil, C, until it overcomes the pull of the upper magnet and pulls the clutch down. When the clutch, A, strikes block, D, and takes the horizontal position, the rod slips through it and the upper carbon is said to "feed." The coil, C, may be wound on the outside of coil, S, but with current in the opposite direction to it, and the result is the same.

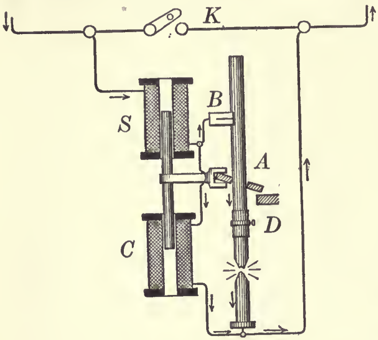


FIG. 147.

In the open arc described above, the carbons at the high temperature of the electric arc (about 3,500° C.) are oxidized rapidly and must be replaced after about 8 hours. In the inclosed arc, used in most of the newer lighting systems, the arc is inclosed in an inner small glass globe which fits rather closely about the carbons to prevent much circulation of air. This globe soon becomes filled with CO_2 instead of O and the carbons are not consumed so rapidly. The carbons in such a lamp will last from 150 to 200 hours, hence much of the expense of "trimming" is saved.

In both the arcs described most of the light comes from the pit formed in the positive carbon, as very little light comes from the arc itself. A type of lamp now coming into use is the flaming arc. The carbons are fed forward at an angle. The carbons have been soaked in some salt, usually calcium floride, or have a core composed of the same salt. The heat of the arc vaporizes the salt and the electricity is conducted on this incandescent gas. The

light is the color caused by the salt used and comes mostly from the arc itself. They are often used two in series on the 110 volt *A.C.* circuit.

For incandescent lighting, where the electricity is to be used in the building, it is quite the common practice to use 220 volt D.C. generator. The lamps are connected in parallel, hence the voltage must remain constant while each lamp takes its own current, and the total current used is the sum of the currents required for each lamp turned on. Where the power must be transmitted for long distances, such as required in lighting a large city from one central plant, this would mean the transmission of large currents. It is found that for a given wire the loss due to heat in the line increases as the square of the current, that is, double the current, and the line loss is four times as large. The loss due to carrying a large current is avoided by using an A.C. generator or alternator and generating current at 2300 volts. This is transmitted over well-insulated bare wires to the city block where it is to be used and then stepped down by a transformer, already described, to 110 volts and distributed to the house for use.

The incandescent lamp used until recently has a small filament of carbon inclosed in a vacuum within a bulb. When the electric current, passes through, this filament is heated to incandescence. The resistance of the carbon decreases as the temperature increases. The carbon lamp requires about $3\frac{1}{2}$ watts per candle-power. About 98% of the power used is lost in heat. Recently filaments made of the element tungsten have come into common use. The resistance of this filament increases as the temperature rises. It requires about $1\frac{1}{2}$ watts per candle-power. The long filament is fragile and must be handled with great care. It is best to burn the lamp in a vertical position,

and even then it is found that the life of the lamp is short if there is much vibration of the fixture. Where the voltage is lower the filament does not need to have so high a resistance and may be made shorter and thicker. For this reason engineers are generally of the opinion that where new buildings are being fitted for electric light it is better to fit them for 40 volt lamps and transform the current 40 volts instead of 110. Where this has been tried the lamps are showing high efficiency and long life. The 110 volt circuit is left because of the old carbon lamp. Space forbids a detailed description of the Nernst lamp and the Cooper Hewitt mercury vapor arc.

The complete circuit for the ordinary lighting circuit is shown in Fig. 148. As shown, the house circuit is not electrically connected to the power-house from which the consumer buys power, but is completely insulated from it. The only connection is the magnetic interlinking in the transformer. For such a circuit the alternating current shown by the curve on page 133, known as single phase, is used.

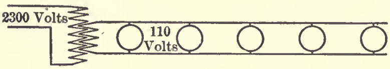


Fig. 148. — Transformer Circuit.

The line circuit is insulated from the house circuit. Both are wound on the same iron core, and change in current in the primary generates the E.M.F. of the secondary.

In considering a wave-motion and when speaking about the A.C. current already shown, we called a complete wave a cycle. In the two-pole machine studied it required a complete revolution of 360°. On a many-pole machine the rotation from a north pole past a south pole and to the position in front of the next north pole produces the same electrical effect as a complete revolution of the two-pole machine. It is, therefore, an electric cycle, and is considered electrically 360°. Phase refers to the position in this cycle. If it has made one fourth of the cycle the phase

is 90 degrees. In the alternator it is common to have the armature stationary and revolve the fields, as in Fig. 149. Suppose the coil were spread out as coil $a-b$ in that figure. Some of the turns of wire will be generating E.M.F. opposed to the rest of the coil and the back pressure will prevent the coil from generating as much pressure as it should. It was early found that if the coil were crowded together, as at d, all the turns of wire would be in the same phase, that is, they would reach the highest point of the curve at the same time and produce the greatest result. But if the turns were crowded together this way they would leave a large part of the ring not surrounded by wire; and to put on more coils and connect them together would only go back to the wide-spread coil $a-b$. If separate coils be put on equally spaced as 1, 2, 3, Fig. 149, the first is almost through the cycle when the third is just starting it, that is, they are in different phase and are really 120° apart on the electrical revolution. In Fig. 150 the E.M.F. generated by each of the three coils is shown by lines 1, 2, and 3. Add the three pressures at any point of the curve and you will find the result zero.

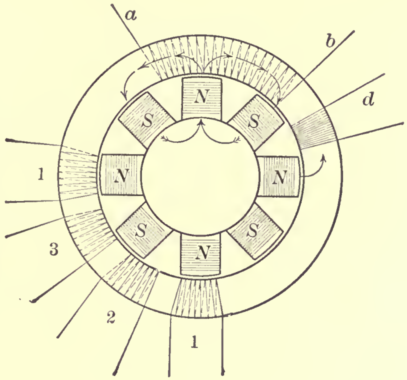


Fig. 149.

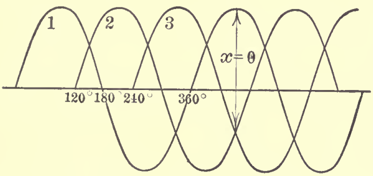


Fig. 150.

The electrician who built the first alternator tried to connect the coils in series and found they would not light

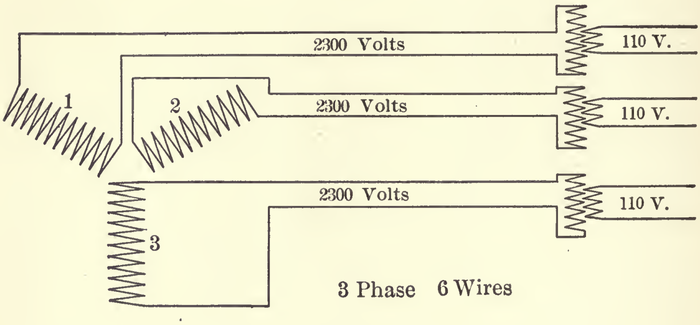


Fig. 151.

lamps while each coil separately would run electric lights. Each coil may be used separately as in Fig. 151, and each makes a satisfactory lighting circuit. There are many alternators in operation, furnishing three separate circuits at 2300 volts each. Such a machine generates as much electricity as three separate machines would do. It takes three times as much power to run it as one set of *c* coils would require, but it takes no more floor space in the power plant than one machine with one set of coils would require.

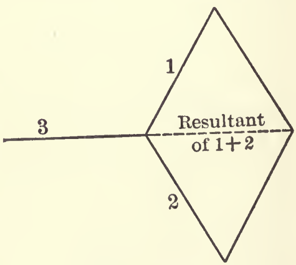


Fig. 152.

If the three are connected together the result is like connecting three equal forces pulling at angles of 120°, as in Fig. 152. The resultant of any two is equal to and opposite

to the third and the result of all three is exactly zero. Electricians have lately found out how to take advantage of this to save wire. The three coils of the alternator are connected together at one end of each and a wire from the other end of each is run out across the city (Fig. 153), and each run through its lighting circuit, and then after running through its useful circuit are all connected together. Each furnishes its own circuit with its full supply of current but, when the three run together, the result is zero, and no return wire is needed. The wire may stop at the union or be grounded as desired. It will be seen that the three wires in this circuit operate as many lights as the six wires above. This is the common three-wire, three-phase system of the present time.

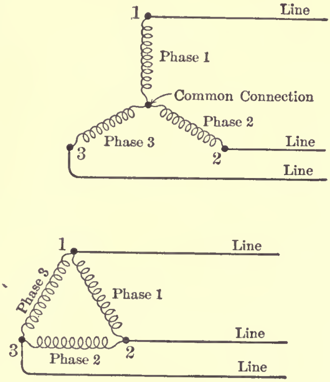


Fig. 153.

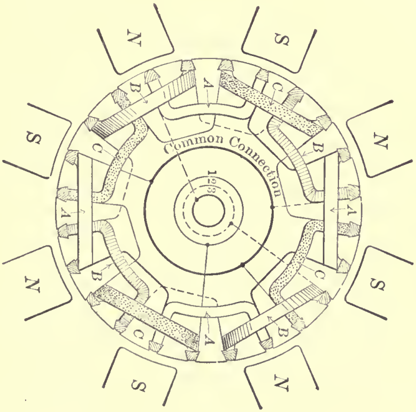


Fig. 154.

Diagram showing coils and their connection in the armature of a three-phase alternator.

The Sanitary District of Chicago develops about 60,000 horse-power at 66,000 volts and transmits it 34 miles to Chicago over three aluminium

conductors. The neutral wire at each end is grounded, but under all ordinary conditions carries no current.

When studying the direct current generator and application of the electro magnet a brief study of the direct current motor was made. Refer to it and read it as a part of this lesson. A direct current generator may be used for a motor. A small direct current series motor may be used on a single phase A.C. circuit, as the current reverses the field at the same time that it reverses in the armature, but for large motors this would not work. In operating the D.C. motor, the shunt type of connection is generally used, except in the street car, where the motor must start under heavy load. In that case series motor is used. The winding of the armature and of the field is practically the same as for a generator, and if the shunt motor were belted to an engine and run up to speed it would act as a generator. When running as a motor, however, the E.M.F. is supplied by an outside source and drives the current through the machine and the magnetic drag of the lines

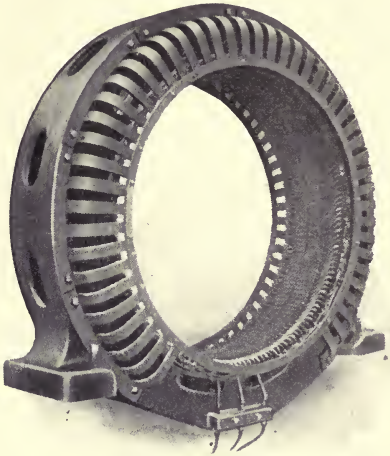


Fig. 155.

From a photograph of the stationary armature of the type of three-phase alternator used to generate most of the electricity used at the present time. Fig. 156 shows the revolving field for this generator. The field is excited by a direct current from a small D.C. dynamo called the exciter. In Fig. 157 the dynamo is shown assembled.

of force pulls the armature around. The resistance of an armature intended to operate on the 220-volt circuit is usually only a fraction of an ohm. Applying Ohm's law would show an enormous current, which would either blow all fuses on the circuit or burn out the insulation of the armature. If the full drop of potential is applied while the motor is standing still this would be the case, but a starting box is connected in series with the armature and as the motor is started the lever of the starting box is moved over slowly. On the first notch the resistance is all in series with the armature, and holds down the current. As the motor gets up speed the lever is moved over on the successive contacts until when the motor has reached full speed the resistance is all cut out and the E.M.F. is all applied to the motor armature, Fig. 158. The resistance is no longer needed because the motor running at speed is acting as a dynamo and generating an E.M.F. in the direction

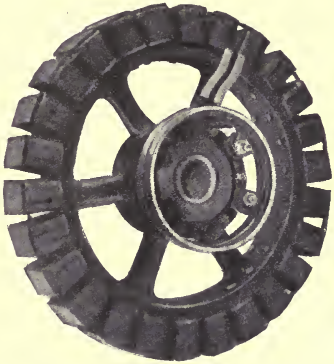


Fig. 156. — The Revolving Field.

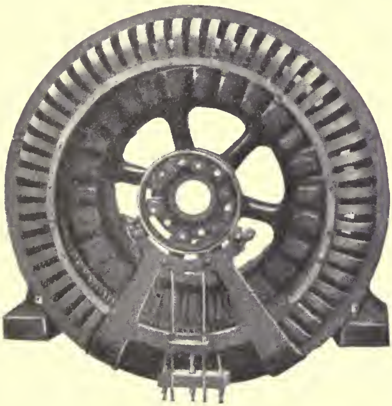


Fig. 157. — The Dynamo.

opposite to that applied, and this back pressure, which is almost equal to that applied, keeps the current from becoming large. In fact, if a motor were a perpetual-motion machine, that is, an ideal machine running without friction and doing no work, the counter E.M.F. would be equal to that applied, and the current zero a condition not reached in practice.

On every street car there is a controller for the motorman which contains a set of contacts to control the current through the rheostat and motors beneath the car. There are on each car, connected to the drivers by a spur gear, either two or four series motors. When the controller is on the first notch the motors are all in series with the rheostat. If run here long much power is lost in heat in the rheostat. The next notches cut out resistance until the fourth and fifth notch. Here the resistance is all out and the motors are in series and at half speed, but no power is lost in heat in the resistance. The next notch throws the motors in parallel and all the resistance of the rheostat is thrown in again. The next successive notches cut out the resistance until on the eighth notch all the resistance is out and the full 550 volts is applied to the motors in parallel, and the motor is furnishing its full

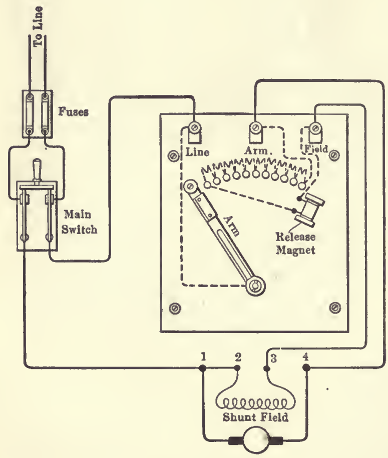


FIG. 158.
Wiring diagram for a D.C. Shunt Motor.

power. The ninth or last notch shunts the field. This weakens the strength of the field magnets. On a level track the car will then run at full speed, as the motor armature must turn faster to cut as many lines of force as before. Weakening the field makes the motor run faster provided it is not too heavily loaded. Except in starting, the car should be run on the running notches to avoid loss in heat in the rheostat. If the controller is thrown over too fast the circuit breaker is automatically

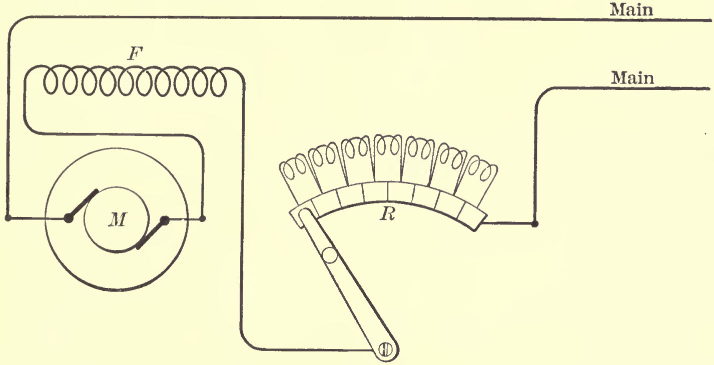


FIG. 159.
Wiring diagram for a Series D.C. Motor.

released and protects the motors from burning out. Some motormen are experts at starting a car smoothly and running in the running notches most of the time. Other motormen are careless and cost the operating company far too much for power wasted in the rheostat. Watch the next motorman you ride with and see if he is using the current intelligently or if he is wasting power and destroying equipment.

The recording watt-meter (Fig. 160) is practically a little motor. To keep it from running too fast a brake

which acts in proportion to the speed must be used. A mechanical brake would act too strongly when the machine was standing still or running slowly and not strongly enough when the meter is running rapidly. In the bottom of the watt-meter shown, an aluminium disk, run by the motor, revolves between the poles of

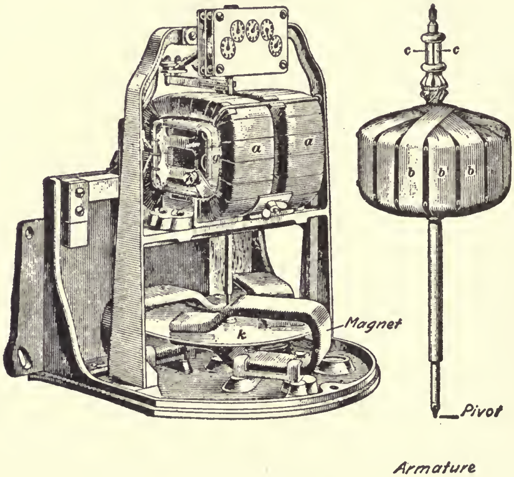


FIG. 160. — The Recording Watt-meter.

This is practically a small motor in which the number of revolutions depends upon the number of kilowatt-hours of electrical energy used. A worm gear moves the pointers which record the power used.

a flat horseshoe magnet. Aluminium is non-magnetic, but when the plate revolves it cuts the lines of force and eddy currents are set up. These eddy currents are in proportion to the rate of cutting lines of force and therefore proportional to speed. The magnet reacts on these and drags them back, acting as a brake. Read

the meter at home, then time it for an hour on a given number of lamps, and see if it is running properly.

We have considered the direct current motor, its use and control, but to be at all up to date we must consider at least two types of A.C. motors. A few years ago one of the leading scientific papers of our country published a long article stating that the A.C. motor would probably never be used except for a few special applications because it would run at only one speed and because it was very unreliable at that. Now they are in common use for all purposes. The use of the two- and three-phase current and the single phase "split," so that it becomes a two-phase current, has brought about this result. Fig. 161 represents a ring of soft iron with a coil of wire connected to a single phase A.C. generator furnishing 60 cycles.

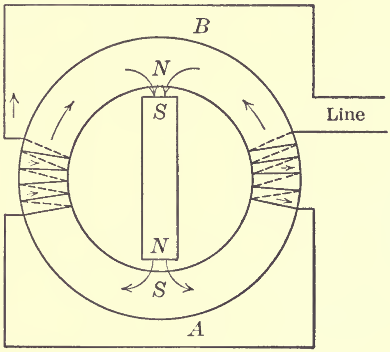


Fig. 161.

A permanent magnet is mounted on a shaft so that it may revolve within the ring. As the current through the coil rises in one direction a north pole is built up at the top of the ring; then it dies out and is built up at the bottom of the ring as the current rises in the opposite direction. This alternation takes place 120 times per second. At one time it is repelling and at the other time attracting the magnet. This action takes place so rapidly that the tendency for the magnet to begin to rotate is gone and the tendency to push it the other way appears before the magnet has had time to start. The result is that

the magnet remains stationary. If, however, it is started and run up to speed, that is, 60 revolutions per second in either direction, the alternating field will give it a pull or push in the same direction twice each revolution and it will run as a constant speed motor. A permanent magnet may be replaced by an electro magnet and the effect will be the same. Such a motor is called a synchronous motor, as it keeps step with the generator. It will not start itself and if overloaded so that it falls behind the generator it

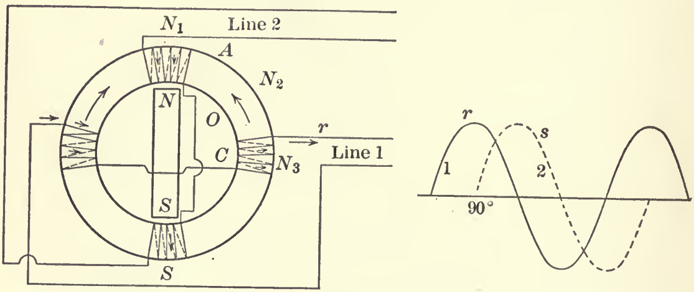


FIG. 162.

will stop. Such motors are of use where a number of machines must run at exactly the same speed and that speed be controlled from one point, the generator.

If we have a two-phase current with one 90° behind the other, as in Fig. 162, and connect to two sets of coils wound on a ring as in Fig. 162, we will have current, r, at its largest value when s is zero, and we will have N_1 as shown in the ring at point A. One-eighth of a cycle later, r will have fallen to half its value and s will have risen to half its value; the resultant will be N_2 pole half way between the two at O. It will have reached that point by moving along the ring from A to O as r has decreased gradually and s has increased gradually. One-eighth of a cycle later r will

be zero and s will be at its highest point, resulting in a north pole at N_3 at C. As the cycle continues the north pole will slide along the ring, making the complete circuit. As it passes the pole of the magnet it will give it a jerk to bring it along with it, and as these impulses are all in the same direction the magnet will start and we will have a self-starting two-phase A.C. motor. The magnet may be replaced by an electro magnet, electrically excited, and the result will be the same. Instead of an electro magnet, that is, an armature excited from without, place an iron core similar to the drum armature with large copper bars placed in the slots around the circumference, as in Fig. 163, with the bars connected so that they resemble a revolving wheel in the squirrel cage. If this replaces the magnet in Fig. 162 it will not be a magnet as long as zero current flows through the coils of the ring. As soon as the current is turned on in the coils on the ring the field begins to run around the ring. We have a field revolving rapidly around a closed circuit loop of wire, and, although that loop of wire has no electric connection with any outside circuit, the revolving field generates a large current in it and this makes a magnet of the iron core, and the field acting on this magnet drags it around and we have a self-starting variable speed A.C. motor known as the induction motor. As elec-

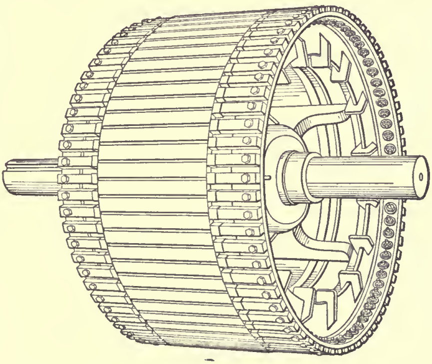


Fig. 163.

Squirrel Cage Rotor of the three-phase Induction Motor.

tricians do not know which to call the armature nor which to call the field, they avoid the difficulty by calling the stationary part the **stator** and the rotating part the **rotor.** The three-phase A.C. lends itself to this type of motor very well indeed, as it requires only three wires for transmission from alternator to motor and by placing the coils uniformly produces a revolving field. Since a revolution means an electric cycle, that is, from one pole past the opposite to the like pole again, these may be placed along the ring to give any speed desired. Such a motor has no sliding contacts, so all commutator and ring troubles are eliminated. A resistance is usually placed in the rotor to prevent too

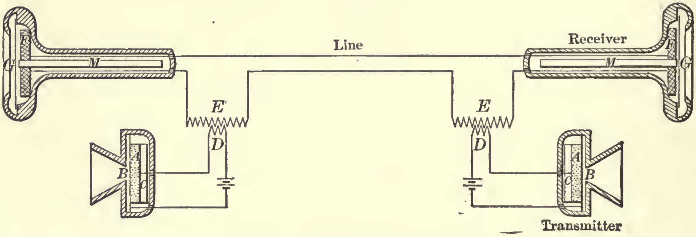


FIG. 164. — Telephone circuit.

The transmitter changes sound waves to a fluctuating current of electricity. These are changed at the receiver to sound, thus reproducing words spoken at the transmitter.

large a current while the motor is getting up speed, and then is automatically cut out by centrifugal force as soon as the motor is up to speed. Many electric railways are now adopting the three-phase induction motor for traction purposes.

The telephone is an interesting application of the electric current to the transmission of messages. In discussing Ohm's law we found that if the applied E.M.F. remains constant while the resistance of the circuit is changed, the current changes accordingly.

If two pieces of carbon are placed in contact and an electric current is sent through them, the resistance changes with every change of pressure. The modern telephone makes use of this fact. Fig. 164 shows a diagram of the essential parts. The transmitter contains a space (*A*) filled with small pieces of hard carbon between two plates *B* and *C*. One of these plates, *B*, is at the base of the mouthpiece and vibrates with every sound wave entering the mouthpiece. This causes the pressure between the carbon particles to vary with every vibration and this causes the current in the primary circuit to fluctuate with the same pulsations that the sound waves make. The primary runs through an induction coil, *D*, and as the induction takes place only with changes of current the secondary, *E*, carries an exceedingly small current fluctuating with every sound vibration; but it is not sound, it is only fluctuating electric current, and would not affect the ear except to shock it; so the receiver is used. It is a permanent magnet with a steel disc, *G*, placed in front of one end of it. *F* is a coil of fine wire wound around the magnet and connected to the line carrying the fluctuating current from the transmitter. This varying current causes the same changes in magnetism, and the steel plate, *G*, reproduces the same vibrations in the air which were received at the transmitter, *B*. The sound is not carried along the wire but is changed to a fluctuating current of electricity, and this is conducted along the wire and at the receiver is changed back to sound.

Historically static electricity was known for hundreds of years before any practical use was made of electricity and for that reason is usually studied first. It has little practical application and will be considered here very briefly, not because of its value, but because most of the boys are interested in it. The principal application is in

the condenser used in wireless telegraphy. At any time some inventor may bring out a practical application which will increase the importance, to the world, of static electricity; there are rumors that Edison has one now.

The Greeks knew that if amber (Greek electron) is rubbed with silk some change takes place around it so that it will attract small pieces of paper. This is the origin of the name electricity. Later it was found that glass rubbed with silk and wax rubbed with fur differed from each other, and the former came to be called positive and the latter negative electricity. Almost any two substances rubbed together will generate electricity but many substances conduct the strain away so it is not detected. When one kind of strain is developed an equal amount of the opposite sign is also generated, that is, when glass is rubbed with silk the positive strain is found on the glass and an equal amount of negative electricity is found on the silk. There is an impression that this electricity is different from the electricity we have been studying generated by dynamos or batteries. This is not correct; it is the same kind of strain. When electricity is flowing along a conductor it is called current electricity and when a body is charged with electricity which is said to be standing still it is called static electricity. When a condenser is charged by a current it becomes static.

A little time spent experimenting with a glass rod, silk, wool, and sealing wax will convince the student that like electricities repel and unlike charges attract each other. If a glass jar is lined with tinfoil, and covered outside with tinfoil, but the two coats left insulated by the glass and a charge of electricity is communicated to one of the coats, it will attract and hold in the other coat an equal amount of the opposite kind and repel an equal amount of the like kind, which will escape if given a chance. To charge a

Leyden jar, connect the outer coat to the earth and then conduct either + or − electricity to the inner coat; the repelled charge will flow to the earth and the bound charge will remain. When charged, a large spark may be obtained by connecting the two coats, so that the two phases of the strain which are trying to get together may unite. A Leyden jar may give a serious shock. If the glass is replaced by paraffined paper and the tinfoil is built up in several layers, first a strip of tinfoil and then a strip of the oiled paper etc., with every other strip of tinfoil connected together at one end and to one pole, while the others are connected together to the other pole, we have a condenser. Some form of condenser is much used in wireless telegraphy, as we shall see later.

A few experiments which every student should work at home and which will lead to a thoughtful understanding of static electricity are the following:

Rub a piece of glass with silk, bring it near some small piece of paper, also bring it near a very small jet of water. Can you explain what you see? Rub a piece of sealing wax with wool or fur. Repeat the experiment you did with the glass. Suspend two small pieces of pith by silk thread and let them touch the electric wax. Explain what you see. When they are electrified from the wax, bring the glass near them.

Scuff your feet along on any wool rug and then touch the gas pipe or any other grounded conductor. It takes several thousand volts to produce a spark one-eighth of an inch long — why did the spark produce no serious results? Let some one else turn on the gas and you can light it with the spark from your finger.

For testing static charges of electricity a gold leaf electroscope is commonly used. As shown in Fig. 165, a flask is fitted with a rod through the stopper and the upper end

terminates in a brass ball while the lower end supports two pieces of gold-leaf. When this is charged the leaves fly apart as shown in the figure because like charges repel. To charge an electroscope by conduction, take a small piece of metal carried on a hard rubber handle and after rubbing it on a charged body touch it to the ball of the electroscope. This will charge the electroscope by conduction. To charge by induction bring any charged body near the ball and the like sign will be repelled to the leaves while the unlike sign will be attracted to the ball. Now touch the ball with the finger and the repelled charge will escape to the earth. Remove the finger and then remove the charged body and the leaves will stand apart, the electroscope being charged with the sign opposite to that of the inducing body.

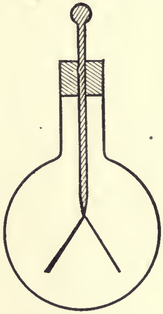


FIG. 165.—Electroscope.

When charged the gold leaves diverge.

Study the influence machine and report on its operation. We found that when a direct current was used in the primary of an induction coil the secondary gave a high potential spark when the primary current was interrupted. This discharge practically all occurs at the interruption of the primary.

A condenser connected to the terminals increases the intensity or "fatness" of the spark. The discharge of a condenser behaves like a spring carrying a heavy weight. When stretched and released it bobs up and down, that is, it vibrates, gradually coming to rest. The spark discharge is similar. It oscillates, as shown in Figs. 166 and 167.

If the ends of the secondary be connected to the ends of a Geissler tube, the discharge is found to be entirely differ-

ent. The Geissler tube is a glass tube with platinum terminals sealed into the ends and the air exhausted to about 1/380 of an atmosphere. The discharge through the tube becomes almost continuous and the gas left in the tube glows with a brilliant color which depends upon the kind of gas remaining in the tube. The light resembles the Aurora display. It has been used to a limited extent in lighting buildings. The Moore light on this principle is now successfully used.

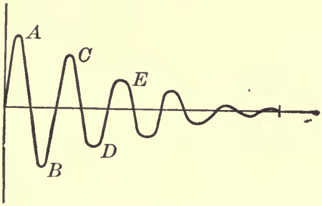


FIG. 166.
The spark from a condenser oscillates as shown above.

When the gas is exhausted to about one-millionth of an atmosphere the discharge undergoes another change discovered by Sir William Crooks. A stream of electrified particles called corpuscles is projected from the cathode in straight lines until they meet the opposite side of the tube and there cause it to glow with a beautiful florescence. These particles cannot pass through the glass and may be deflected from their course by a magnet. Röntgen found that when these particles of the cathode rays strike on glass, or better on a platinum screen placed in their path, they give rise to a different kind of ray or vibration, which he called the X-ray. These rays will pass through glass, paper, cardboard, wood, etc., but not through metal or bone. They will

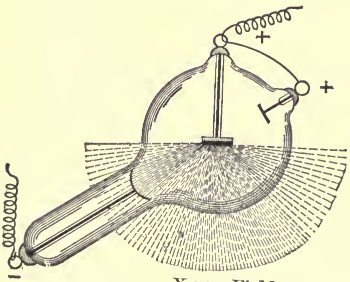


FIG. 167.

affect the photographer's plate as light does, hence when a photographer's plate is placed in a plate-holder or box and the hand laid on the box and exposed to the X-ray, the ray will pass through the flesh and the box but not through the bones and a shadow picture of the bones and any metal imbedded in the hand will be taken (Fig. 168).

FIG. 168.
X-ray picture of the Hand of a Child.

As the X-ray does not affect the eye, the shadows cannot be seen by the eye, but if a screen coated with calcium tungstate is placed back of the hand it becomes luminous where the rays strike it and hence the shadow picture of the bones may be seen. This is much used in examining bone diseases and imbedded bodies such as bullets. The X-ray is much used in treatment of cancer and similar diseases. It should be used with great care, as exposure to the X-ray often causes serious burns which are not felt at the time but develop later and cause the flesh to slough away. The operator continually exposed to the rays is protected by lead shields which stop the X-rays.

The photographer can take a flash-light of moving object, because the light from the burning powder is of such short duration that during the time of exposure the object

moved only an inappreciable distance. Recently a scientist has taken a series of pictures of the splash when a weight is dropped into water. It was soon found that for such a rapid event as this, the flash-light was too slow and uncertain, hence he used an electric spark. We think of the electric spark from the condenser or Leyden jar as being almost instantaneous. Investigation shows that discharge or spark behaves much like a spring carrying a weight. When the spring is stretched and released, it goes beyond the point of rest and vibrates back and forth until it gradually comes to rest. The spark from the condenser or Leyden jar does the same thing as though it were a stretched spring. Possibly it is some form of strain in ether. The frequency of the alternations of the discharge depends upon several conditions but is often about 230 million per second. The conductor leading to the spark gap has a current reversing 230 million times per second. It is a well-known fact that a magnetic needle near a wire carrying a current tends to turn at right angles to the wire. If the current is reversed the needle swings in the opposite direction. If this alternation takes place 230 million times per second, the needle would not have time to keep up, but we can imagine a strain or impulse in the ether sent out and reversed that many times per second. This would be a wave motion in ether and would travel out through space much as light waves do. These waves were discovered by Professor Hertz and are called the Hertzen rays. They always accompany an electric discharge, are continually passing through space and through your body. Some one may be telegraphing a message through your body now, and you never know it. As these waves cannot be seen, felt, nor heard, they were long undiscovered. These senses of ours are very dull. We know little about this world of ours; we suspect a few things and

now and then some one finds out some new fact about things about us. The eye can detect a few ether vibrations; the others have existed all these hundreds of years and now we have found only a few of them. Here we have a poetry of motion surpassing any poetry ever written by man, a machine so wonderful in its fine mechanism that although the wisest men since the time of Adam have been studying it, we have to admit to-day that there are many of the parts we do not know how to use and that we know only a little about our surroundings. The true scientists can only wonder at the marvelous intelligence of a being capable of making the working drawings and constructing such a mechanism that man with all his boasted powers of thought can understand only a little of it.

To lead up to an understanding of the Hertzen ray we will summarize a few vibrations with which we are already familiar.

Ear:
- 16 vibrations per second, lowest sound
- 32 vibrations per second, lowest musical tone
- 128 vibrations per second, man's conversational voice
- 512 to 256 vibrations per second, woman's conversational voice
- 2000 vibrations per second, high soprano
- 4000 vibrations per second, highest musical tone
- 40,000 vibrations per second, highest audible sound

Ether vibrations:
- Trillions vibrations per second, X-ray
- 2000 billion vibrations per second, photographic ray
- 750 to 400 billion vibrations per second

Eye: Violet
Indigo
Blue
Green
Yellow
Orange
Red (about 33,000 to make one inch)

230 million vibrations per second Hertzen ray used in wireless. (The frequency often becomes much less than

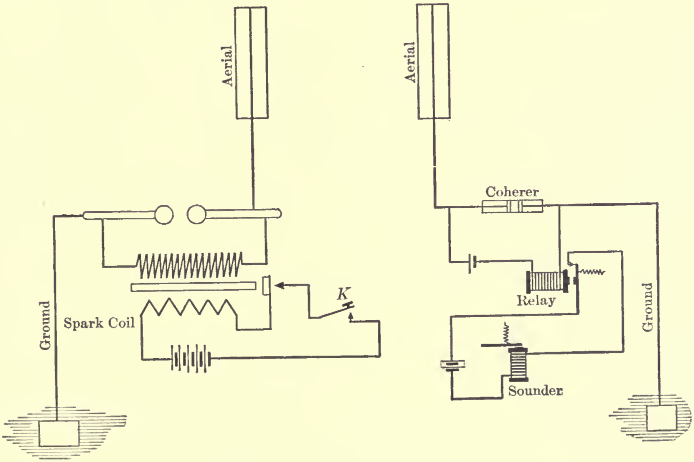


Fig. 169.

Simple form of Marconi apparatus for wireless telegraphy. The coherer is not very sensitive and is now replaced by a detector. Ether at the sending station is vibrated by a spark. These waves travel out as light waves do and set up electric vibration in the receiving circuit.

this as the waves vary from a few feet to over a mile in length.)

There are many forms of apparatus and many helpful devices such as tuning coils, condensers, electrolytic inter-

rupters, electrolytic detectors, etc. But the essential features of the Marconi system are shown in Fig. 169. At the sending station an induction coil or transformer is used to produce the high tension to cause a spark.

The discharge of the spark causes an oscillating current in the aerial with a frequency of some 230 million oscillations per second. The frequency may be varied by the size of the coil or transformer and capacity of the condenser. This pulsating charge in the wire will send out vibrations of ether which travel out in all directions. At the receiving station a coherer is so connected that the vibrations received by the aerial pass through it to the earth. A variable capacity or else a tuning coil must be used to make the receiving station of the same frequency as the sending station, so that sympathetic vibrations will be set up. For detailed description of all parts of the apparatus the reader is referred to Popular Electricity for 1910.

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